OKLAHOMA GEOLOGICAL SURVEY

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PRELIMINARY REPORT

ON THE

LEAD AND ZINC

OF

OKLAHOMA

By L. C. SNIDER

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CHAPTER I.

THE NATURE, COMPOUNDS, OCCURRENCE AND USES OF LEAD AND ZINC.

PROPERTIES OF THE METALS.

Lead is a soft, heavy metal of a blue-gray color, (which takes its name lead-gray from the metal) with a bright metallic luster on fresh surfaces. On exposed surfaces it tarnishes to a dull, dark gray. It has a hardness of 1.5 of the Moh's scale, which means that it is easily cut by a knife and can be scratched by the finger nail. Its specific gravity is 11.37. Its fusibility is 1 of Von Kobell's scale, which means that it fuses easily in a luminous lamp or gas flame, or in a closed tube below red heat (344° C. or 633° F.). At a red heat it volatilizes rapidly. It is malleable and can be hammered into thin sheets though not so thin as silver or gold, and is easily rolled into sheets which are pliable. It is ductile though not to a pronounced degree and can be drawn into only tolerably fine wires. Lead is always more or less impure unless made by special processes. Lead and all its compounds are poisonous.

Zinc is a white, lustrous metal on fresh surfaces, but tarnished surfaces are a dull, light gray. Its hardness is greater than that of lead, 2 in the mineral scale, and its specific gravity is 7.17. It melts at a dull red heat, 410°-430°C., and volatilizes at 1000°C. At ordinary temperatures it is brittle but becomes somewhat malleable and ductile at 100°-150°C. At 200° it again becomes brittle. Zinc is easily oxidized and the coating of oxide remains on the surface protecting the metal beneath from further oxidation. It is this property which renders zinc valuable for many of the uses to which it is put. Chemically, zinc is an active element and displaces several of the other metals from their compounds.

HISTORY OF LEAD AND ZINC.

The history of lead and zinc is discussed in some detail by Winslow in Volume VI of the Missouri Geological Survey. This volume is unfortunately out of print but the historical portion has been reproduced in Volume VIII of the University Geological Survey of

Kansas. In the present report a brief abstract of Winslow's paper is given and the reader is referred to the two reports mentioned above for more complete detail, and for the bibliography.

History of lead. Lead and its properties have been known for a long period, reaching back to the beginning of history. In America, lead does not seem to have been separated from its ores in prehistoric times. No lead is found in the mounds of the Mississippi Valley. The Indians probably learned the reduction of lead from the white men.

In Africa and Asia lead has been worked since the beginning of historical times. The earliest Egyptians used it for many purposes, and the Chinese were acquainted with the metal as early as 2000 B. C. Important deposits of silver-lead ores in Asia Minor and in India were worked in very early times.

In Europe lead mining began along the shores of the Mediterranean where the knowledge of the metal was acquired from the east. The famous lead mines at Laurium in Greece were probably worked as early as 1200 B. C., extensively worked in the 6th and 5th centuries B. C., and to a more limited extent down to the beginning of the Christian era. Mining was revived in this region in 1865.

The Phoenicians and Carthaginians worked the mines of southern Spain and probably those of northern Spain, southern France, Sardinia and Sicily. After these countries were conquered by the Romans the latter continued the lead mining in these regions and extended the operations into France and England, southern Italy and perhaps into Austria. Some of these mines have been revived in comparatively recent times and are still being worked.

There seems to have been little mining of lead in Germany in early times. Mining in the Harz Mountains seems to have begun in the 10th century but was not active until the 15th. The Silesian mines were producing in the 13th century. The German mines have been actively exploited since the 15th and 16th centuries. In Belgium mining was begun at an early period and continued to be an important industry up to comparatively recent times. The mines are practically exhausted at present. In Russia, mining operations on an extensive scale were not commenced until the 16th and 17th centuries. Lead mining in Great Britain was commenced by the Romans and continued less actively by the Saxons and Danes, but the production first became important about the 15th century and has continued up to the present.

In North America the earliest lead mining was in Mexico where the Aztecs mined the silver-lead ores before the Spanish conquest. The Spaniards began mining here in 1520 but the most important

development was after 1700. Since 1821 mining has been a very active industry principally through the influence of English and American capital.

Lead mining was begun in the United States near Jamestown, Virginia. The Wythe County deposits in the eastern part of the state were discovered in 1750 and have been worked intermittently up to the present. Some lead was mined in the New England States, New York, and Pennsylvania prior to 1850 but very little has been produced east of the Appalachian Mountains since that time. The production of these states has not reached 100 tons of metallic lead in any year since 1907.

Lead ore was found in the Mississippi Valley about 1700. The development of the southeastern Missouri ores began at Mine La Motte in 1720. It was much later before the ores of the Joplin district were discovered. These were not known before 1850 and were not developed until 1870. A more detailed history of this district is given in another connection. The northern Mississippi Valley ores in Iowa, Wisconsin, and Illinois were worked slightly from 1790 to 1821. In these states the industry became very important in 1840 to 1850 but has declined since that time, while zinc mining has increased in importance. In southern Illinois and the adjacent parts of Kentucky mining began about 1840 and was most active from 1865 to 1875.

Practically all of the important silver-lead deposits of the western states have been discovered in the last half-century. The principal deposits in Utah and Nevada were discovered between 1860 and 1870. In Colorado, the Georgetown deposits were discovered in 1866,, the Leadville deposits in 1874 and the Aspen deposits about 1880. In Idaho, the Idaho City deposits were discovered about 1867, the South Mountain deposits about 1871, the Wood River in 1872, and the important Coeur d'Alene deposits were found about 1880, although the value of the lead deposits was not recognized until a few years later.

History of zinc. Although zinc as a metal is a product of recent times, its ores have been known for a considerable period. The ores, principally the silicate and the carbonate, were used in the production of brass before the Christian era. It is probable that the metal was first found as an accidental product in the furnaces used in producing brass. The first intentional production of zinc in Europe was about 1720 although it has been produced in Asia as early as the 16th century. Works were established in England in 1743 and on the continent in Silesia about 1798. The Belgian process of reduction was established in 1809 but it was not until 1820 that the manufacture of zinc in Europe became a well established industry.

Very little zinc has ever been produced in South America and in North America outside of the United States.

In the United States the zinc ores usually accompany the lead ores, but in the early days of mining in this country the zinc ores were not recognized and their value was unknown. In many cases they were mined with the lead ores but were discarded, and no use was made of them until early in the 19th century. Zinc was first manufactured at the arsenal at Washington in 1838 from the red oxide ore of New Jersey, which had been discovered in 1820. Works were established at Newark, New Jersey, in 1848, and at Bethlehem, Pennsylvania, in 1853. For some time zinc white was the only product from the Pennsylvania ores but in 1860 the metal was obtained on a commercial scale. The Virginia and Tennessee ores were not utilized until after the Civil war. In the upper Mississippi Valley the zinc ores were first smelted at La Salle, Illinois, in 1860 although they were known for some time previous. Zinc was manufactured in Missouri in 1867 at Potosi, and in 1869 at Carondelet. The use of ores from the Joplin district began in 1871 and the first ore from this district was shipped to La Salle but smelters were built at Weir City and Pittsburg, Kansas, in 1873. The first smelters in southwestern Missouri were built at West Joplin in 1881.

The recovery of zinc in the western states has been largely incidental to the working of the ores of other metals, especially those of lead and silver, and its history is closely connected with that of the development of the lead ores which has already been briefly noted.

MINERALS CONTAINING LEAD.

The principal minerals containing lead as an important constituent are galena, cerussite, leadhillite, anglesite, pyromorphite, and minium. Besides these there are several other lead minerals which are so rare or which occur in so small quantities as to be of no value as a source of lead.

Native lead. Lead is very rarely found in the native state. It sometimes occurs in very small quantities where it has been reduced from the sulphide or other minerals. It also occurs in a few metorites.

Galena (PbS) is the sulphide of lead, containing, when pure, 86.6 per cent lead and 13.21 per cent sulphur. It is of a bright lead-gray color with a metallic lustre. It crystalizes in the orthorhombic system and has a perfect cubic cleavage. The form of occurrence is in imperfect cubes although octahedral forms are sometimes found. The specific gravity is 7.4 to 7.6; hardness, 2.5; and fusibility, 2. In nature galena is always more or less impure, silver and the sulphides of zins, copper, cadmium, and bismuth being the principal impurities,

Galena, which is called "mineral" or "lead" by the miners is by far the most important ore of lead.

Cerussite ($PbCO_3$) is the carbonate of lead, containing when pure, 16.5 per cent of carbon dioxide and 83.5 per cent of lead oxide or 77.5 per cent of lead. Its color is variable, ranging from white through gray into black, and is sometimes tinged blue or green by the presence of small amounts of copper compounds. The lustre is adamantine. Cerussite crystallizes in the orthorhombic system, and occurs as plates, prisms and in tabular forms, is sometimes compact or earthy in irregular shapes or may be granular, stalactitic or fibrous, or a powder coating galena. Its fracture is conchoidal; cleavage, distinct; specific gravity, 6.55; hardness, 3.35; fusibility, 1.5. Cerussite is probably formed through the oxidation of galena to lead sulphate and the subsequent action of surface waters carrying carbon dioxide on the sulphate. It generally contains small quantities of silica, iron and clayey matter as impurities. As an ore of lead it ranks far below galena in importance but is of considerable value locally.

Anglesite ($PbSO_4$) is the sulphate of lead, containing, when pure, 26.4 per cent sulphurtrioxide and 73.6 per cent lead oxide or 68.3 per cent lead. It crystallizes in the orthorhombic system and is prismatic, tabular or pyramidal when crystalline. Anglesite occurs in small quantities in cavities in galena crystals, is sometimes stalactitic, but is more commonly massive, granular or compact. It often forms a powdery coating on galena and crystals of galena may be largely altered to anglesite, leaving only a kernel of galena inside of concentric layers of anglesite. The color is white, pale yellow to pale green; lustre, adamantine, vitreous or resinous; cleavage, distinct; fracture, conchoidal; hardness, 3; specific gravity, 6.35; fusibility, 2.5. Anglesite seldom occurs in sufficient quantities to be important as an ore of lead.

Pyromorphite ($(3Pb_3PO_4)_2.PbCl_2$) is a phosphate of lead, containing 76.3 per cent of lead. It may be green, brown, yellow, gray, or white in color, and has a resinous lustre. It crystallizes in prismatic forms of the hexagonal system. When not crystalline it may be botryoidal, reniform, fibrous, granular or massive and earthy. Fracture is irregular; specific gravity, 6.5-7.1; hardness, 3.5-4; fusibility, 2. Impurities are often present, the principal ones being lime, arsenic, chromium, and iron. It is not important as an ore of lead.

Other minerals. In addition to the ones named above a large number (about 50) of other minerals contain lead, but they are never abundant enough to serve as a source of the metal. Among these are the hydrous sulpho-carbonate, leadhillite; the chromates, crocoite, phoenichloite, and vangueinite; the molybdate, wulfenite, the arsenate, mimetite; the vanadates, vanadinte and descloizite; the oxide minium, and many others.

MINERALS CONTAINING ZINC.

Native zinc has been reported in Australia, in Georgia and in California[1] but it is extremely rare.

Sphalerite or zinc blende (ZnS)is the sulphide of zinc containing when pure, 33 per cent of sulphur and 67 per cent of zinc. Pure sphalerite is almost colorless but it usually contains sufficient iron to give it a yellow or brown and sometimes black color. Green and lead blue sphalerite also occur. This mineral is transparent to translucent with a resinous to adamantine lustre and it crystallizes in dodecahedral forms of the isometric system, very commonly twinned. It occurs in imperfect crystals, isolated, or in large masses with well developed cleavage, in fine grained or compact masses, or disseminated through the various country rocks with which it may be associated. It may also be found lining cavities in the rock or as stalactites. In the Joplin district it is sometimes found as a white clay-like substance in pockets where it has apparently been re-deposited from solution. Sphalerite is brittle with a conchoidal fracture and with well developed cleavage in the large crystalline masses. It is specific gravity is 4.05; hardness, 3.5-4; fusibility, 5. At very high temperatures sphalerite volatilizes, apparently without passing through the liquid condition. Iron and manganese are very common impurities, while lead, copper, cadmium and silver are less commonly present. It is by far the most important ore of zinc, and is often known as "jack," "black jack" or "resin jack."

Calamine ($Zn(OH)_2\ SiO_3$) is the hydro-silicate of zinc, containing 54.2 per cent of the metal. It is colorless to pale green, blue, or brown, transparent to translucent, with a vitreous lustre. It crystallizes in the orthorhombic system, in tabular and prismatic forms, or grouped in sheaf-like forms. It occurs in mammillary and granular forms, in sheaf-like aggregates, lining cavities and in masses in clay. The cleavage is perfect along some faces; fracture, uneven; specific gravity, 3.45; hardness, 4.5-5; fusibility, 5. Clay is the principal impurity but iron and other metals may occur in small amounts. Calamine is probably formed by the action of surface waters upon sphalerite and is an important ore in workings above the level of ground water. It is known to the miners as "jack" or gray jack (in some districts) and as "silicate."

Smithsonite ($Zn\ CO_3$) is the anhydrous zinc carbonate, containing 52.03 per cent of zinc. It is normally colorless, but is often gray and may be tinged, brown, green or blue by impurities, and is translucent with a vitreous lustre. It crystallizes in the hexagonal system but is usually botryoidal and also occurs in stalactitic, incrusting and compact granular or earthy forms, resembling those of calamine. It

1. Winslow, Mo. Geol. Surv., vol. VI, p. 24.

oftens forms psendormorphs after other minerals. Smithsonite is brittle with an uneven fracture. Its specific gravity is 4.30-4.35; hardness, 5; fusibility, very high. Iron, manganese, magnesium, calcium and cadmium compounds are common impurities. Smithsonite is often intimately mixed with calamine and with clay. It is an important ore of zinc in some localities (Northern Mississippi field) where it occurs near the surface in the oxidized zone. The miners of this field commonly call it "dry bone" ore, although the same term is applied to the lead carbonate, cerussite, in other districts.

Hydro-zincite ($ZnCO_3 2Zn(OH)_2$) is a phosphate of lead, concontaining 60.47 per cent of zinc. It is white, gray or yellowish in color. While it may occur in crystalline masses it is usually earthy or compact. Its specific gravity is 3.6-3.8; hardness, 2-2.5; fusibility, high. It is of rather common occurrence but is usually in too small quantities to be of any importance as an ore.

Zincite (ZnO) is the oxide of zinc, containing 80.3 per cent or the metal. The color of the native zincite is orange to deep red with adamantine lustre. Specific gravity is 5.43-5.7; hardness, 4-4.5; infusible. Zincite is usually an original mineral and is of rare occurrence. It is important as an ore only in the Franklin Furnace district of New Jersey.

Willemite (Zn_2SiO_4) is the anhydrous zinc silicate containing 58.62 per cent of zinc. The color varies from white to greenish through gray, yellow and brown to red. Willemite is transparent to opaque with a resinous lustre. Its specific gravity is 3.89-4.18; hardness, 5.5. The mineral is not abundant in nature and is produced as an ore only in the New Jersey field.

Other minerals. Franklinite, the ferrate of zinc is a black mineral with metallic lustre. It is common in some of the New Jersey zinc mines but is otherwise very rare. *Zahnite* or zinc spinel is an aluminate of zinc occurring at several localities but in small quantities. There are many other minerals of zinc but they are so rare and occur in such small quantities that they are of no importance from an economic standpoint.

OCCURRENCE OF LEAD AND ZINC IN THE UNITED STATES.

In this connection the general conditions of the occurrence of lead and zinc ores and the principal deposits of these metals in the United States are briefly noticed. The deposits of the Joplin district, of which the Oklahoma area is a part, are considered more fully in a succeeding chapter.

Classes of Deposits.

There are three general classes of lead and zinc ores: (1) those practically free from copper, silver and gold, (2) those carrying silver and gold with usually some copper in addition, and (3) the lead-silver ores which consist of galena or oxidized ores containing notable amounts of silver. The second and third groups are confined to the Rocky Mountain and Western States while ores of the first group occur in the Mississippi Valley and in the Eastern States.

Modes of Occurrence.

"Zinc and lead ores may occur under a variety of conditions, viz: (1) as true metalliferous veins; (2) as irregular disseminations, formed by replacement or impregnation in limestones or quartzites; (4) in contact metamorphic deposits; (5) in cavities not of the fissure vein type; and (6) in residual clays."[2] The famous zinc ore deposits of New Jersey belong to the second class, the ores of the remaining Eastern States and of the Mississippi Valley principally to the third, fifth and sixth classes and those of the Western States to the first, second, third and fourth. While the deposits of both the Mississippi Valley and the western region contain examples of the third class (irregular masses or disseminations produced by replacement of limestone or quartzite) the origin of this type of deposit in the two regions is very different as will be noticed in the discussion of the different producing areas.

Nature of Ores.

As has already been noted the principal ores of lead and zinc are the sulphides, galena and sphalerite. These minerals may be original constituents of igneous rocks but in ore deposits are almost invariably deposited from aqueous solution. While in solution the metals are probably in the oxidized form as sulphates, but are precipitated as the sulphides by the mixing of the solution with reducing solutions or by the solution coming into contact with reducing agents. Organic matter is usually regarded as the principal reducing agent but several other substances probably play an important part in the reduction.

After the sulphides are formed the surface of the ground is lowered by erosion and the upper parts of the deposits may be exposed. Part of the ores may be carried away and lost if erosion is rapid but probably the greater part of the ores near the surface, which are affected by surface waters, are oxidized to the sulphates and carbonates. These are dissolved and carried downward by percolating waters. When these reach lower levels they encounter reducing conditions and the

2. Ries, H., Economic Geology Of the United States, p. 427.

metals are again precipitated as the sulphides. This process. greatly enriches the deposits at the level of the precipitation and is known as secondary sulphide enrichment.

In the majority of deposits of lead and zinc ores, then, the ores at a depth greater than that reached by the oxidizing waters from the surface, will be principally galena and sphalerite, while above this level the ores will be principally the oxidized ores, cerussite, calamine and smithsonite, with usually some unoxidized galena and sphalerite.

Geographic Distribution.

In the United States the ores containing lead or zinc or both in association with copper, silver, and gold are confined to the Rocky Mountain and Western States, principally Idaho, Colorado, and Utah; the ores containing lead and zinc or lead alone, without the precious metals occur in the Mississippi Valley, principally in southwestern Wisconsin and adjacent parts of Iowa and Illinois, and in southern Missouri and adjacent parts of Kansas, Oklahoma and Arkansas; the ores containing zinc alone or zinc with some lead and without the precious metals occur in the eastern states, principally in New Jersey and in Virginia.

Geologically, lead and zinc ores occur in small quantities in the rocks of all geological ages, but most of the important deposits are in the Paleozoic group and especially in rocks of the Cambrian, Ordovician and Mississippian ages. There are some important deposits in pre-Cambrian rocks.

Description of Producing Areas.

EASTERN STATES.

New Jersey[3]. The zinc ores of New Jersey occur in Sussex County. Two ore bodies, one at Mine Hill near Franklin Furnace and one at Sterling Hill near Ogdensburg, two miles to the south are worked. Both ore bodies are spoon or trough-shaped bodies lying in metamorphosed pre-Cambrian limestone. The Mine Hill deposit is near the contact of the limestone with the gneiss but the Sterling Hill ore body is about one-fifth mile from the outcrop of the gneiss. These deposits have been known since about 1650 and in 1838 the first zinc manufactured in the United States was made from the Mine Hill zincite at the United States arsenal at Washington. It was not until about 1850 that active development began. For several years the ore was used in the manufacture of zinc oxide but in 1860 the manufacture of spelter from the ore was placed on a commercial basis and development has proceeded rapidly since that time.

3 Spencer, A. C., Franklin folio (No. 161), Geol. Atlas U. S., U. S. Geol. Survey.

The ores of these bodies are unique in that they consist of the oxide of zinc, zincite, the anhydrous silicate, willemite and a mixture of the oxides of zinc, iron and manganese, franklinite. These minerals are very rare in other localities and there is no other place in which they occur in this association. Some calamine and smithsonite were produced from near the surface. The ore bodies are usually called veins but are really layers in the limestone which are not sharply separated from the barren rock. The ore bodies are cut by pegmatite dikes. Various theories have been proposed to account for the origin of the ores, but the matter has not been definitely settled. It is generally held that the ores have been derived from the limestone subsequent to its deposition. The folded (trough-like) form of the bodies is considered due to their formation along a certain horizon in the limestone after the folding rather than to their formation before the folding took place. The deposits are cut by pegmatite dikes of later age. The contact metamorphism caused by these dikes has produced an extraordinary number of minerals, many of which are extremely rare except in this locality. The production from these two deposits has been very great and kept New Jersey second in the list of zinc producing states for several years. Large quantities of both zinc oxide and of spelter are produced and spiegeleisen is made from the franklinite after the separation of zinc.

Virginia-Tennessee Belt. In the folded region of western Virginia and eastern Tennessee there are some deposits of lead and zinc ores which have been worked in a small way. The ores are associated with the Knox dolomite of Cambro-Ordovician (Ozarkian) age. They occur in two ways: (1) as oxidized ores, cerussite, calamine and smithsonite in residual clay, and (2) as galena and sphalerite in fault breccias and along the axes of anticlines where the rock has been broken and brecciated[4]. This district has not so far been important as a producer, but promises further development.

Pennsylvania[5]. "The Saucon Valley deposits promised at one time to become prominent producers, but have not, owing more to geological conditions than to actual scarcity of ore."

MISSISSIPPI VALLEY.

Upper Mississippi Valley District.[6] This district includes the southwestern portion of Wisconsin, small areas in the northeastern portion of Iowa and northwestern Illinois. The lead and zinc ores occur principally in the Galena formation, a dolomitic limestone of Ordovician age. The Galena limestone and dolomite is underlaid by the Platts-

4. Nelson, Wilbur A., Resources of Tennessee, vol. 2, No. 3, March, 1912.
5. Ries, H., Economic Geology of the United States, p. 436, 1910.
6. Bain, H. Foster, Bull. U. S. Geol. Survey No. 294.

ville limestone and overlaid by the Maquoketa shale. The ore occurs in cracks and crevices and in solution channels and pockets of the Galena and also disseminated as a replacement of the dolomite.

The rocks generally dip to the southwest at low angles but there are variations in the dip and also broad low folds. The principal ore deposits are localized in the synclines

The ores are galena and sphalerite, the former being the more abundant in the higher levels and the latter increasing in proportion with depth. Marcasite is associated with the ores and materially lowers the grade of the zinc concentrates. This difficulty has been overcome in some measure by the introduction of electrostatic separation. It is believed that these ores were derived from the overlying Maquoketa shales which have been largely removed by erosion, and also that they were collected by circulating waters within the Galena itself, and were precipitated in the Galena by reducing solutions mingling with the ore bearing solutions.

Western Kentucky District.[7] This field occupies all of Crittenden, Livingston and Caldwell counties in western Kentucky. The ores, smithsomite, sphalerite and galena are found in rocks of Mississippian age, in fissure veins which have been produced by faulting and as metasomatic replacement of limestone. The lead and zinc ores are associated with large fluorspar deposits and are obtained principally as a by-product in the fluorspar mining. Basic dikes occur in the region but are not generally believed to have had any great influence upon the deposition of the ores.

Southeastern Missouri District.[8] This district which comprises the major portions of St. Francois, Washington and Madison counties, is one of the important lead producing districts of the United States. The ore is galena which occurs for the most part in the lower half of the Bonne Terre formation, magnesian limestones and dolomites of Cambrian age. The galena is principally a disseminated ore. It is believed to have been derived from the formations overlying the Bonne Terre and to have been carried down into the Bonne Terre by percolating waters and precipitated there by reducing agents, probably by the dolomite itself. Upward moving waters under hydrostatic pressure from the underlying LaMotte sandstone have probably added to the ore deposits.

The Joplin District in southwestern Missouri and adjoining portions of Kansas and Oklahoma is the most important zinc producing area, and is also a prominent producer of lead. This field is considered in detail in a succeeding chapter.

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7. Smith, W. S. Tangier, Prof. Paper U. S. Geol. Survey No. 36, 1905.
8. Buckley, E. R., Missouri Bureau of Geology and Mines, vol. IX.

Northern Arkansas.[9] The Cambro-Ordovician limestones and dolomites of northern Arkansas contain some deposits of lead and zinc which have been worked on a small scale for many years, but which have never become important producers.

ROCKY MOUNTAIN AND WESTERN STATES.

In the Western States the ores are much more complex than in the eastern and Mississippi Valley regions. They usually carry gold and silver, copper, manganese and other metals. They are almost invariably associated with faulting, folding, and in the majority of cases with igneous intrusions from which the ores have been derived. Zinc is much less abundant than lead and the production of the western states is small compared to that of the eastern and central states. Only the more important of the deposits are noticed in this connection.

Idaho.[10] Idaho has for some years been either the first or second state in the production of lead. The principal production is from the Cour d'Alene district which lies on the western slopes of the Cour d'Alene Mountains in the northern part of the State. The lead deposits are metasomatic fissure veins of galena in a thick series of pre-Cambrian shales, sandstones and quartzites. Monzonite dikes are associated with the deposits and the ores are thought to have been deposited from hot solutions rising from the intrusions. The galena carries much silver, about one-half ounce for each per cent of lead per ton. The bulk of the ore ranges from 3 to 14 per cent lead and 2.5 to 6 ounces of silver per ton. It is concentrated to about 50 per cent lead. Sphalerite and pyrite accompany the ores but little zinc is produced. The galena reaches a known depth of 2600 feet but the deposits become poorer at 1000 to 2000 feet. The upper portions of the ore bodies are oxidized. The district also contains workable gold and copper deposits.

Colorado. In south-central Colorado the Leadville camp has been one of the important producers for many years. The lead and zinc ores, consisting principally of galena and sphalerite and their oxidized products, occur as replacement masses in Silurian and Mississippian dolomite and dolomitic limestones and in fissure veins in Cambrian quartzite. The region is strongly folded and faulted and there are large intrusions of porphyry. The ores were deposited subsequent to the intrusions and previous to the faulting. Emmons[11] states that the ores were derived from the neighboring igneous rocks, by downward circulating waters, and were deposited by replacement. It was his belief that the original source of the ores might have been at great depth. Other writers believe that the ores were derived directly from the underlying pre-Cam-

9. Adams, Geo. I., Prof. Paper U. S. Geol. Survey No. 24.
10. Ransome, F. L., Prof. Paper U. S. Geol. Survey No. 62.
11. Mon. U. S. Geol. Survey, vol. 2; Bull. No. 320.

brian granite by an upward circulation. The lead and zinc ores carry gold and silver and are associated with manganese, copper and bismuth ores.

Mines at Creede, Colorado, furnish lead and zinc (galena and blende) which occur in fissure veins.

At Aspen, silver-lead ore is found in limestone of Carboniferous age at the intersection of two sets of faults. Spurr[12] believes that the ores were deposited from magmatic waters which moved upwards along these intersections, precipitation being due to the reaction between the magmatic waters and the wall rocks. Silver and lead are the only metals produced at this mine and the former is the more important.

The ores at Rico occur as lodes, replacements in limestones, stocks and blankets, i. e. deposits usually lying parallel to the bedding planes or to the sheets of igneous rocks. The geologic section includes rocks ranging in age from pre-Cambrian to Jurassic, which are faulted and intruded by igneous rocks. The Hermosa formation of Carboniferous age is the principal lead bearing horizon and galena is the lead producing ore.

Utah.[13] In Utah the two principal lead producing camps are the Park City district and the Tintic district.

The Park City district is located 25 miles southeast of Salt Lake City. The rocks consist of about 6000 feet of sedimentaries mostly of Carboniferous age, in general dipping southwest but traversed by many fissures, faults and intrusions. In the oxidized zone the ores are cerussite, anglesite, azurite, malachite, and in the sulphide zone, galena, tetrahedrite and pyrite. They occur as fissure veins and as replacement bodies in limestone.

About 65 miles southwest of Salt Lake City lies the Tintic district. Here the rocks consist of a thick mass of Paleozoic sedimentaries which were folded and eroded before being covered by Tertiary lavas and tuffs. The ores occur in zones in the limestones, as fissures in the igneous rocks and along the contact of the two. Argentiferous galena, carrying a little copper and gold, is the principal ore.

Other states. The Eureka district of Nevada was once one of the most important producers but is principally of historic interest now. Montana has several camps producing silver-lead ore but none of them are as large as the ones which have been described. The same is true of New Mexico.

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12. Mon. U. S. Geol. Survey, vol. 31.
13. Ries, H., Economic Geology of the United States, p. 464 et seq.

PRODUCTION OF LEAD IN THE UNITED STATES.

The production of lead in the United States for the year **1906** to 1910 inclusive in short tons is given in the following table. These figures do not include the antimonial lead produced nor the lead contined in pigments made directly from the ore[14]:

STATE	1906		190,		1908		1909		1910	
	Quantity	Per cent. of To al	Quantity	Per cent. of Total	Quantity	Per cent. of Total	Quantity	Pe cent of Total	Quantity	Per ct. of Total
Missouri	111,075	31.91	122,856	33.77	122,451	39.57	142,650	40.40	161,659	43.43
Idaho	117,117	33.65	112,569	30.94	98,464	31.82	97,183	27.57	99,924	26.84
Utah	56,260	16.16	61,699	16.96	42,455	13.72	64,584	18.30	57,081	15.33
Colorado	50,497	14.51	48,876	13.43	28,728	9.28	29,326	8.32	35,685	9.61
Nevada	1,699	.48	3,380	.93	3,796	1.23	4,698	1.33	2,195	.59
Wisconsin	1,753	.50	3,551	.98	4,013	1.30	3,238	.92	3,884	1.04
Oklahoma .			404	.11	1,409	3.45	2,268	.64	1,805	.48
Other states	11,752	2.79	11,831	2.88	9,446	2.63	9,994	2.46	9,694	
Total ...	350,153		365,166		310,762		354,188		372,227	

The total production from domestic ores for the United States in short tons in previous years is indicated below. These figures include the antimonial lead but omit the lead in pigments made directly from the ores.

Years.	Amount.
1825 to 1868	676,200
1870	17,830
1875	59,640
1880	97,825
1883	143,957
1885	129,412
1890	143,630
1895	165,709
1900	208,466
1901	269,266
1902	276,455
1903	290,194
1904	308,603
1905	318,509

PRODUCTION OF SPELTER IN THE UNITED STATES.

Zinc in the crude metallic form in which it comes from the smelter is known as spelter. The production of spelter from ores from the different states for the years 1906 to 1910 inclusive in short tons is as follows:

14. Mineral Resources of the United States, U. S. Geological Survey.

STATE	1906 Quantity	1906 Per cent. of Total	1907 Quantity	1907 Per cent. of Total	1908 Quantity	1908 Per cent. of Total	1909 Quantity	1909 Per cent. of Total	1910 Quantity	1910 Per ct. of Total
Missouri	130,348	65,27	141,824	63.99	123,655	64.83	140,676	61.10	140,652	55.71
Colorado	32,456	16.25	26,077	11.66	24,885	13.06	20,121	8.74	23,238	9.20
New Jersey	11,206	5.61	13.573	6.07	6.926	3.63	16,085	6.97	20,217	8.01
Wisconsin	11,057	5.54	15,273	6.83	17,538	9.19	20,381	8.85	19,752	7.82
Kansas	3,902	1.96	13,850	6.19	8,628	4.52	9,185	3.98	10,220	4.05
Oklahoma			719	.32	2,235	1.17	3,088	1.31	2,297	.91
Montana ...	1,415	.71			900	.47	4,725	2.05	12,408	4.91
Utah	2,449	1.23	1,972	.88	282	.15	5,960	2.59	7,221	2.86
Other states	6,861	3.43	10,457	4.34	5,700	2.88	10,134	4.41	16,474	6.53
Total ..	191,694	100.00	223,745	100.00	190.749	100.00	230,225	100.00	252,479	100.00

About 60,000 tons of zinc oxide are produced annually in the United States, of which 90 per cent or more is made directly from the ore and the zinc contained in the oxide is not considered in the above table.

METHODS OF PROSPECTING, MINING AND CONCENTRATING.

(Joplin District.)

Geological conditions under which the ores of the Joplin district occur render it unique among the important mining regions of the world. The shallow depth at which the ore is found makes thorough prospecting much cheaper and also makes the outlay for shaft sinking much less than in most other localities. Owing to the discontinuous or "pockety" occurrence of the upper ore bodies it is not feasible to erect large central concentrating plants as is the case in most mining districts, but is more economical to concentrate the ores in small mills which can be easily moved. The low grade of many of the sheet-ground ore bodies prohibits the shipping of these ores to a centrally located concentrating plant, but they may be handled profitably by plants of 100 to 400 tons daily capacity located at the mines. The abundance of fuel, water and transportation facilities makes this plan of concentration in many small mills more feasible than in the mining camps of the western states. The shallow depth at which the ore occurs and the relative ease with which the rock is worked make it possible to prospect and even to open a mine with a limited amount of capital so that the Joplin region has been known for years as a "poor man's camp."

Prospecting.

In recent years prospecting has been done almost entirely by means of the churn drill. Formerly shafts were sunk in localities which, from surface indications, were considered favorable and drifts driven from

the bottom of the shaft. The use of a drill saves a great deal of time and expense in locating the ore bodies and at the present time shafts are not sunk until the drill has shown the presence of the ore, and something as to its thickness and extent. For detailed prospecting the drill holes must be close together and in many cases strings of holes 15 to 20 feet apart are drilled. The cost of churn drilling varies with conditions but in most parts of the Joplin district the cost for holes less than 300 feet falls between $1.00 and $2.00 per foot. In the Miami camp where the surface rocks are soft shales and sandstones the cost of drilling is reported to be as low as 50 cents per foot for the first 200 feet, but in these cases the drilling rig belonged to the owners of the leases and depreciation of machinery and interest on the investment were probably not considered. Core drills have been used to only a small extent in the Joplin district and not at all in the Oklahoma field.

Mining.

Shafts are sunk after the presence of a considerable ore body is shown by the drill. Drifts are driven from the bottom of the shaft principally by the method known as under-hand stoping. The ore after it is blasted loose is shoveled by hand into cans or tubs, of sheet steel, (occasionally of wood) holding 500 to 1000 pounds of ore. These cans are on small trucks running on steel rails and are pushed by hand to the foot of the shaft. The drifts are driven so that there is a slight fall from the working face to the foot of the shaft. Two or three hundred feet is considered the maximum length for the drifts since in the shallow workings it is considered cheaper to sink another shaft and to haul the ore to the mill in tram cars on the surface, than to have so long a haul underground.

Ventilation gives little trouble and usually no especial effort is made to procure forced ventilation. A second small shaft is sometimes sunk to produce a circulation through the workings when they become very extensive. *Pumping* is necessary in almost all of the mines. Various types of steam pumps are used but where the amount of water to be raised is large the use of the centrifugal pump is becoming common.

From the bottom of the shaft the cans are hoisted by wire cables attached to a drum at the top of the derrick or head frame. At the top the can passes through an opening in the floor of the dumping room, provided with a trap door (which is closed by the operator of the hoist after the can passes it. Each can is fitted with a ring at the bottom. While the door is being closed, the operator fastens a hook, which is suspended by a rope from a beam or rafter of the roof into this ring and releases the drum so that the top of the can is lowered a few feet while the bottom is held by the rope, thus dumping the can.

Milling and Concentrating.

The ore is poured from the can onto a "grizzly," a coarse screen made of 60 or 80 pound iron rails set about 6 inches apart. The pieces of ore less than 6 inches in dimension fall between the rails into the ore bin and the larger pieces are broken up by hammers until they will pass through. Large pieces of barren rock are sorted out, thrown onto a small car and dumped from a short track on a trestle. Two men are usually employed in breaking the ore so it will pass through the grizzly and in sorting out the large pieces of barren rock.

At the shafts other than the mill shaft the ore bin empties into tram cars which are hauled to the mill, usually by wire cables attached

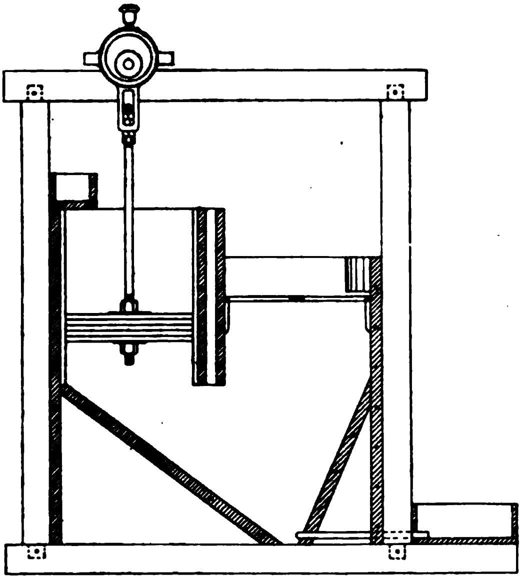

Fig. 1. Transverse section of power jig (after Crane)

to hoisting drum. These cars are self-dumping with the front end so it can be lifted from place. At the summit of the incline to the top of the ore bin the rails of the track turn to the horizontal, while rails which are set on the outside of the track rails continue the incline. The front wheels follow the horizontal rails while the rear wheels, which are wider, follow the inclined rails upward thus lowering the front end of the car so that what may be termed the end gate is drawn up by the cable and the ore dumped.

At the mill shaft the ore is fed from the bin to a jaw or Blake crusher and the crushed material goes to the rolls, of which there are

usually two or three sets which reduce the ore to the proper size. Screens are placed after each set of rolls so that the over size material is returned to the rolls. The finer material is sent directly to the jig.

The jig (fig. 1) consists of a large tank, ordinarily built up of two by fours, which is divided by partitions into (usually) six compartments or cells. Each of these cells has a partition built from the top almost half-way to the bottom. In the front part of the cell a horizontal screen or grating is set firmly, the grating of each cell of the six being two or three inches lower than that of the preceding one. In the back part of the cell a plunger fitting the compartment tightly is worked up and down by an eccentric on a shaft. This gives the water with which the jig is filled an up-and-down motion in the front compartment. The ground ore is washed on to the screen of the first compartment and the pulsating movement of the water causes the heavy lead (galena) to settle to the bottom and fall through the screen into the lower part of the compartment which has sloping sides converging toward the bottom. From this bin the concentrates, "hutch", are drawn off through a spigot into a trough from which they are shoveled into cars on a small track which leads above the storage bins outside the mill. The lighter chats and sphalerite are washed over into the next cell and in this and the succeeding cells the sphalerite is removed in the same manner as the galena is in the first cell while the chats are continually rolled forward and at the lower end of the screens are elevated and washed down a sluice way to the tailing pile. In the tailing mills and in some standard mills a preliminary concentration is effected in a rougher jig, which is constructed in the same way as the ordinary cleaner jig, but instead of the material passing from one compartment to another, each cell is fed independently and the overflow and discharge as well as the "hutch" is taken from each separately.

The fine or slime material is screened from the crushed ore before the water enters the jig and is carried to Wilfley tables. The tables are set at an angle with the horizontal, are provided with riffles, for part of their length, and have a reciprocating backward and forward motion. The ore and water are fed along the upper side and the chats being lighter are carried down over the riffles into a discharge trough, while the galena and sphalerite being heavier are caught and by the motion of the table are carried to the end where there are no riffles. Here they become arranged in definite lines (fig. 2) in the order of their specific gravities, the lead toward the top of the table. A fairly sharp separation may be made between the galena and sphalerite but when pyrite is present it cannot be sharply separated from the sphalerite since the specific gravities of the two are so nearly the same that they travel along the table almost together. The pyrite tends to concentrate in the upper portion of the stream of zinc and this portion is often separated and run back over the tables. Some sphalerite is car-

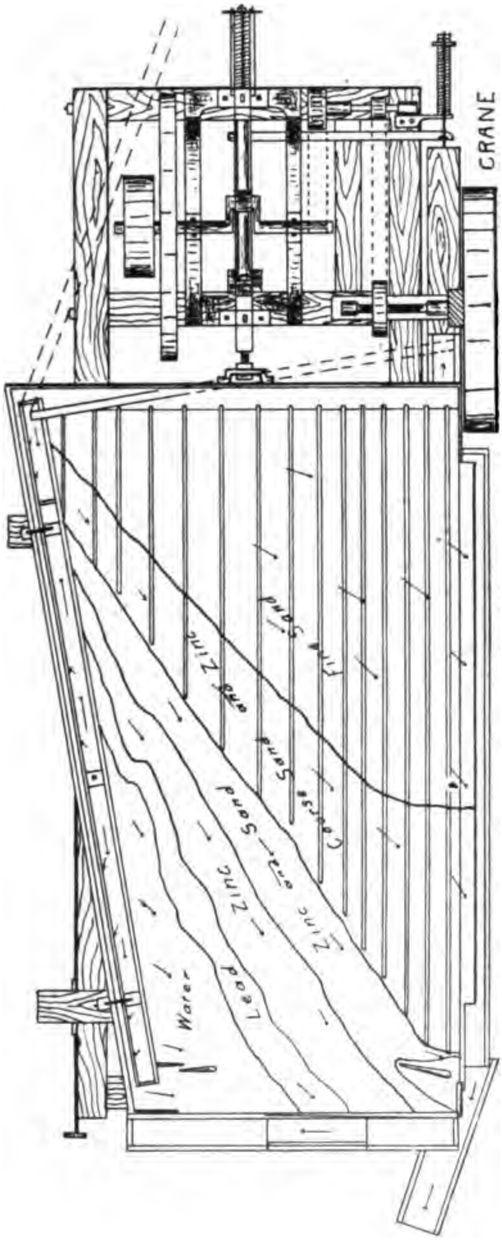

Fig. 2. Plan of Wilfley Table, showing separation of minerals.

ried by the coarse sand which passes to near the end of the table, and this material may also be returned to be worked over. The galena and sphalerite are caught in boxes provided with overflow pipes. From these boxes the concentrates are shoveled into small cars and wheeled to the storage bins.

The brief description given above applies to the ordinarily well equipped mine and mill in the northeastern Oklahoma field. There is considerable variation in the equipment of different mines and mills. In the early stages of development of a mine and in cases where the extent of the ore body is too small to justify the expense of erecting a mill, a hand jig may be used for concentration. The ore may be hoisted by a hand or horse windlass or by a small hoist driven by a gasoline engine or steam engine, which also drives the crusher and rolls. From the rolls the crushed ore is shoveled into the jig.

The hand jig (figs. 3 and 4) consists of a tank, 8 to 10 feet square and about two feet deep. The tank is well constructed, bound by plank and angle iron. Upright posts are bolted to the middle of opposite sides of the tank and extend about two feet above the top; the top of the posts are notched to form a bearing for a cross beam. At right angles to this beam is attached a long lever or arm, which is braced to the beam. The braces extend beyond the beam and from their ends is suspended a rectangular trough which hangs inside the tank. This trough is about one foot deep and is provided with a screen-grating bottom. The tank is filled with water usually from a launder or feed pipe and is provided with an overflow pipe. A plug at the bottom of the tank allows it to be completely emptied.

To operate the hand jig the lever is pulled down so that the trough is brought above the water and held there by fastening the end of the lever to a small post. The trough is then nearly filled with the crushed ore and the lever is released so that the trough comes under the water. By means of the lever the trough is then rapidly raised and lowered under water. By the action of the water through the slotted bottom of the trough, the materials in the trough become arranged in the order of their specific gravities, the lead (galena) at the bottom, sphalerite next, and the chats at the top. After the jig is worked a few minutes, the trough is raised from the water, the chats are shoveled off and the trough refilled with ore. When a good bed of ore has accumulated it is shoveled out and placed in a storage bin. A lever is placed on top of the tank on the side oposite the trough. This lever has a long hook which may be hooked into an eye hole on the trough. Then when the lever is drawn back and locked the trough is pulled to the middle of the tank so that the ore which has fallen through the screen may be shoveled up from the bottom of the tank. The lever which gives the up and down motion to the trough, is worked by hand, or may

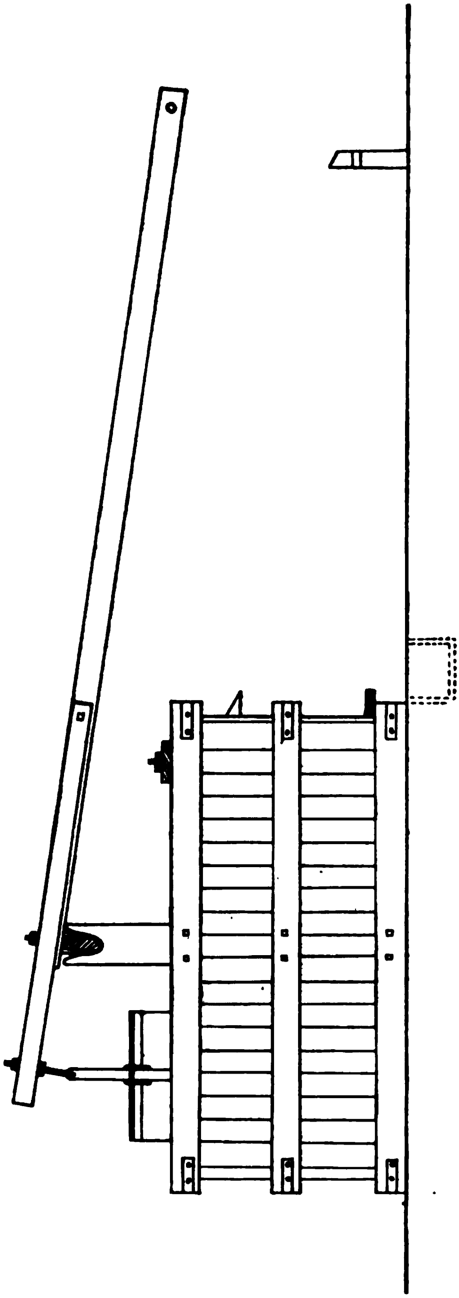

Fig. 3. Side view of hand jig.

be operated by a crank shaft from the engine when one is used for hoisting or for crushing the ore. It will be seen that the same principle of separation is used in the power and in the hand jig but that in the power jig the screen is stationary and the water is given a pulsating movement by a plunger, while in the hand jig the water is stationary and the pulsation is produced by rapidly lowering and raising the screen through the water. When properly worked the hand jig is a very efficient instrument and a surprisingly large amount of ore can be handled by it.

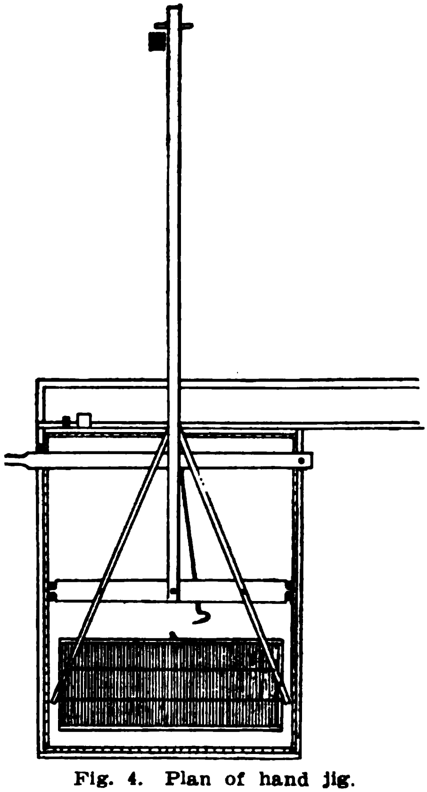

Fig. 4. Plan of hand jig.

Electrostatic and Flotation Methods of Concentration.

The great difficulty in the working of zinc ores is the great loss which results from the methods in use both in concentration and in smelting. The average recovery in the Joplin district is not over 60 to 65 per cent of the contents of the ore, and the zinc concentates contain so many impurities that a zinc content of 60 per cent is considered the standard although pure sphalerite contains 67 per cent of zinc.

These impurities lessen the percentage of zinc which is recovered in smelting, and consequently lower the price of the concentrates. This, as well as the direct penalty imposed on some impurities, such as iron, makes anything which will facilitate producing higher grade concentrates without too greatly increasing the cost of production, of great importance. The low grade of the zinc concentrates in the Joplin region is due principally to the presence of small quantities of sand (crushed chert) and of iron pyrites.

As has been noticed, the specific gravities of sphalerite and pyrite are so nearly the same that a perfect separation cannot be made by any process depending on the difference of specific gravity alone as a principle of separation. The difference in the specific gravities of the sphalerite and the gangue minerals (chats) except where barite is present is sufficient to effect a complete separation if the minerals are perfectly separated in crushing. This condition, however, is not realized, and is far from existing when the sphalerite is well disseminated through the country rock. A particle of material, even after tolerably fine grinding may contain both chert and sphalerite. Such particles when the sphalerite is in excess usually go into the concentrates, carrying the chert with them and lowering the grade of the concentrates, and when the chert (or other gangue mineral) is in excess they go into the tailings, carrying the sphalerite with them, thus reducing the percentage of recovery.

Fine grinding reduces the ore so that the sphalerite and country rock are divided in the crushed material. However, the very fine ground material requires more time in jigging, increases the amount of ore to run over the tables, and produces more finely divided galena and sphalerite which float off and are lost with the tailings. Other factors also enter into the separation of finely ground ore so that the fine concentrates are often of lower grade than the coarser and very seldom are enough higher in grade to offset the cost of the extra grinding and the extra time required in separation.

The needs of the situation, therefore, are means of concentration which will remove the pyrite and also make a cleaner separation between the sphalerite and the non-metallic substances.

The first part of the problem has been in a measure met by roasting the concentrates to a sufficiently high temperature to render the pyrite magnetic but not high enough to drive off any of the sulphur, and to pass the roasted product on conveyor belts under strong magnets which remove the pyrite. So far, this has not been attempted at the concentrating mills in Oklahoma. Some of the smelters of the Joplin region are equipped with the machinery for making this separation and make a specialty of buying concentrates high in pyrite and removing the pyrite, thus materially raising the grade of the concentrates and in-

creasing the yield of zinc when they are smelted. The separated pyrite is used in the manufacture of sulphuric acid and commands a price of 3 to 4 dollars per ton.

Instead of roasting the concentrates and separating the pyrite by magnetic means, the electro-static separation may be used with unroasted concentrates. This process is briefly described by Siebenthal as follows[15]:

ELECTROSTATIC SEPARATION.

"The process of roasting and magnetic separation continues to be used for the separation of pyrite from blende on account of cheapness, simplicity, and effectiveness of separation; but electrostatic separation has made great advances for such purposes. The principle of electrostatic separation is that materials which are good conductors, passing over a surface highly charged with electricity (an electrode) will be rapidly charged with like electricity and will consequently be repelled. Poor conductors, on the contrary, will be slowly affected and will drop nearly perpendicularly from the field. A separation is thus made, which may be made sharper by passing the concentrated material over a surface charged with the opposite electricity, when the charge in the good conducting material is reversed and the material is rapidly repelled, while the poorly conducting material, being charged with opposite electricity, is drawn to the electrode surface. Among the good conductors are nearly all the metallic minerals, and among the poor conductors are zinc blende and zinc carbonate, and nearly all gangue minerals and country rocks. Thus the process is especially adapted to make the difficult blende-pyrite separation."

The solution of the problem of better separation of the sphalerite from the siliceous country rock seems to be in an application of the flotation methods. These methods and their application in Europe and Australia are described by Siebenthal in the paper just quoted and his description is given here:

FLOTATION METHODS.

"The main feature of development in ore dressing during 1908 was the successful employment of flotation methods in practical use. Several of these methods had demonstrated their efficiency in experimental tests and a few in actual practice, but it was not until the latter part of 1907 that they were accounted completely successful and only in 1908 that they were widely employed. They have received their chief application in Australia and Europe, but have had several experimental tests and a few practical trials in the United States.

15. Siebenthal, C. E., Mineral Resources of the United States, for 1908, Pt. I, U. S. Geol. Survey, 1909 p. 256.

"Although the physics of ore flotation is as yet somewhat obscure, it is generally conceded that the principles concerned deal with the mechanics of the free surface of a liquid in contact with solids, and include adhesion, surface tension, and superficial viscosity, the latter more particularly in the case of the McQuisten process, to be described later. The liquid in question is water, and the free surface exists at the periphery of the bubbles of air or of carbonic acid gas, as well as at the upper surface of the liquid. In both cases the surface film of water resists rupture by different minerals with different degrees of strength, varying inversely with the adhesion of water to these different minerals. The greater the adhesion of water to the mineral the more easily it is wetted; the less the adhesion of water to the mineral the more it resists wetting. This property of resistance to wetting is the primary factor in ore flotation. Thus, the surface film of water resists rupture by the sulphides (or the sulphides resist wetting)most strongly, by the ordinary gangue minerals less strongly, and by quartz scarcely at all. It is found that these differences are emphasized if the material to be treated is mixed with oil, the adhesion of which to sulphides and gangue material is the reverse of that shown by water. Moreover, oil being lighter than water, is itself an active agent of flotation. Oil also assists in flotation by serving to agglomerate the sulphide particles.

"If carbonic acid gas be generated from the gangue minerals by the addition of sulphuric acid to the tank in which the ore is being treated, the small rising bubbles selectively attach themselves to the particles of metallic sulphide introduced at the bottom of the tank and float them to the surface, where they are drawn off as an oily metallic scum, the gangue settling to the bottom. The selective attachment of the gas bubbles, upon which the success of the flotation and concentration depends, is a measure of the degree of adherence of the gas bubble to the different sulphides and gangue minerals; and that in turn is an inverse measure of the adhesion of water for the same particles. The particle of sulphide for which water has least adhesion—that is, which resists wetting most strongly or with which water has the largest angle of capillarity—will on coming in contact with the gas bubble be forced farther into the bubble, with resulting greater adherence to it.

"Among the means used to accelerate the process and effect a more perfect separation are deepening the tanks, heating the liquid, and partially exhausting the air above the liquid in the tank.

"The forces employed in ore flotation are most delicately balanced. Consequently in any given case the process to be worked will require adjustment to the character of the ore by careful experimentation. This undoubtedly accounts for the local failure of flotation processes elsewhere successful. The zincy tailings so well treated in Australia seem especially adapted to flotation. Experiments indicate that this suc-

cess is largely due to the proportion of gangue to sulphide and to the presence of manganese and iron carbonates in the gangue. Experimentally the clean zinc concentrates refused to float. Upon the addition of the requisite amount of inert gangue the flotation was successful. But on the addition of an excess of inert gangue all sulphides, including the zinc sulphide, sank. As to the presence of an air film enveloping the sulphide particle and the part this film plays in the flotation there is difference in opinion. The papers of Messrs. Swinburne and Rudorf[a] and of Professor Huntington more over[b] while rather sharply opposed as to interpretation of the general facts of ore flotation, offer about the only available experimental data. These papers and their discussion comprise a general exposition of the subject from several points of view. As has been shown in the foregoing notes, the field of flotation concentration is limited to the separation of the minerals which resist wetting (generally the metallic sulphides) from the easily wetted minerals and gangue. Where two or more minerals are floated, a further separation must be made, magnetic or table, as the case may necessitate.

FLOTATION IN AUSTRALIA.

"In the Broken Hill district of Australia there are large accumulations of zinciferous tailings, the result of years of exploitation of the zinciferous silver-lead ores. By various authorities these heaps of tailings are estimated to amount to about 6,000,000 or 7,000,000 long tons, and to contain about 1,200,000 long tons of zinc, 350,000 long tons of lead, and 40,000,000 ounces of silver. Several of the companies mining these ores have developed flotation processes, more or less similar and all employing the buoyancy of air or carbonic acid gas bubbles. The oxidized and weathered tailings are somewhat harder to handle than the fresh tailings, but the addition of sulphuric acid to the solution cleans off the oxidized film and renders the sulphide particles subject to the forces of flotation.

"The importance of Australian competition in the production of zinc ore justifies a brief description of the principal flotation methods in use in that country. According to a table published in the London Mining Journal, the recovery of zinc concentrates from zincy tailings, both new and old, in the Broken Hill district in 1908 was as follows:

a Swindlburne, J., and Rudolf. The physics of ore flotation: Trans. Faraday Soc., vol. 1, pt. 4, pp. 336-344.

b Huntington, A. H., The concentration of metalliferous sulphides by flotation: Trans. Faraday Soc., vol. 1, pt. 4, pp. 346-355.

Production of zinc concentrates at Broken Hill, New South Wales, in 1908, by companies and processes.

Company.	Process	Tailings. Long tons.	Concentrates. Long tons.
Sulphide Corporation	Ballot	182,340	98,000
Broken Hill Proprietary	Potter	276,703	64,373
Zinc Corporation	Elmore	131,965	45,707
Minerals Separation Co.	Ballot		32,197
De Bavay's Treatment Co.	De Bavay	74,187	22,590

"The Broken Hill Proprietary Company (Limited), with a dump pile of 3,000,000 tons of tailings, first used the Delprat process, employing a dilute solution of salt and sulphuric acid as the agent of flotation. Litigation between this process and the Potter dilute sulphuric acid process, resulted in a compromise by which the Proprietary Company obtained the right to use the Potter process, and the owners of the Potter process were granted the use of the Delprat patents elsewhere in Australia. The plant operated by the Proprietary Company, now using the Potter process, has an annual capacity of over 50,000 tons of 42 per cent zinc concentrates.

"The Sulphide Corporation (Limited), operating the Central mine, has a tailings stack of over 1,000,000 tons. The tailings are worked by the Minerals Separation Company operating the Sulman-Picard-Ballot process, in which the tailings are mixed with a small quantity of oil or oleic acid and some mineral acid and then violently agitated with the water in the flotation tank, the sulphide concentrates rising in a froth. Two plants are in operation, one upon the weathered tailings, the other upon the current product of the mine. The total daily capacity is about 1,200 tons of tailings.

"The zincy tailings from the Broken Hill North mine are handled by the DeBavay process. In this process the tailings, in the form of a thin paste, are gasified with carbonic acid gas and fed upon inclined tables which discharge into a trough where the sulphides float off and are carried to the bin for concentrates. The carbonic acid gas used may be ordinary flue gas. This process is slower, more complicated, more delicate, and apparently more expensive than the other processes, but is claimed to effect an almost perfect saving of the zinc. The De Bavay's Treatment Company has also acquired 370,000 tons of tailings from the Broken Hill Proprietary Block 10 Company and the current tailings output of the Broken Hill South Silver Mining Company.

"The Zinc Corporation (Limited) was formed to acquire the stocks of old zinc tailings. Among the tailings purchased were those of the Broken Hill Proprietary Block 10 Company, Broken Hill South Silver Mining Company, British Broken Hill Proprietary Company, and Broken Hill Proprietary Block 14 Company, amounting in all to over

2,000,000 long tons. These, with the current output of various mines already contracted for, are estimated to be sufficient to supply the present plant eleven years. The method used in the Elmore vacuum process, employing oil and dilute sulphuric acid, the flotation being assisted by a partial vacuum. The plant has a capacity of 806 tons of tailings per twenty-four hours. The tailings assay 20 per cent zinc, 5.75 per cent lead, and 8 ounces of silver to the long ton. The concentrates from the vacuum separation are treated on 20 Wilfley tables, which make 2 products, assaying as follows: (a) Zinc, 46.5 per cent; lead, 7.25 per cent; and silver, 16 ounces to the long ton; (b) lead, 58 per cent; zinc, 15 per cent; and silver, 39 ounces to the long ton.

FLOTATION IN EUROPE.

"The Elmore vacuum process has been installed in a considerable number of European mines, chiefly to separate copper sulphides from various gangue minerals, but in some instances to recover zinc blende.

FLOTATION IN THE UNITED STATES.

"Several systems of flotation have been developed in the United States and the Elmore and McQuisten processes have been tried at a number of places in the United States, as shown below.

"The 'Criley and Everson oil process' was tried at Baker City, Oreg., in 1890, to separate sulphide ores from their gangue.[a] The crushed ore was mixed with black, thick oil and added to water slightly acidulated with sulphuric acid and heated to near the boiling point. The sulphides rose to the surface in a thick scum, leaving clean quartz gangue behind. No details of further commercial utilization of the method are available.

"The Sanders flotation process was first tried in western Kentucky to make the difficult separation of zinc blende from fluorspar. The crude ore, containing lead, zinc, and fluorspar, is crushed and screened through a 20-mesh screen, after which it is passed to concentrating tables of the Wilfley type, which make three products—lead concentrates, zinc-fluorspar middlings, and fluorspar tailings. The middlings go to the flotation tanks, where they are gently agitated in a bath of neutral or basic aluminum sulphate (alum) at a temperature of 85° to 90°C. Small bubbles of gas, said to be H_2S, buoy the sulphides to the surface and float them off into the settling tank. The recovery of the zinc contents of the middlings is claimed to be from 80 to 90 per cent, and the cost of the flotation treatment is put at 34 cents per ton—both estimates as determined in a test upon western Kentucky fluorspar-lead-zinc ore at the plant in Marion, Ky. An equipment consisting of 2 flotation tanks, each of 100 tons capacity, employing the Sanders

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a. Eng. and Min. Jour., vol. 50, Nov. 15, 1890, p. 581.

process, was installed in 1908 in the concentrating plant of the Tri-Bullion Smelting and Development Company at Kelly, N. Mex., to separate blende and pyrites.

"The original McQuisten process is a water flotation method pure and simple, but a later patent provides for the supplementary treatment of the tailings with oil. No acid or gas enters into the flotation. The machinery consists of a tube, 1 foot in diameter and 4 to 6 feet in length, which is slowly revolved with the horizontal axis slightly lower at the discharge end. The finely ground pulp is fed in at the upper end of the tube, the inside of which shows a closely coiled spiral groove. As the thin pulp discharges into the tube some of the sulphide particles are caught and held on the surface of the water by the surface tension and superficial viscosity of the water.

"The more easily wetted gangue minerals and the sulphides which do not float sink to the bottom of the tube; caught in the spiral grooves, the sunken material by the revolution of the tube is lifted above the surface of the water again, when another portion of the sulphides is floated. By the repetition of this action the surface of the water near the discharge end of the tube becomes covered with a dusty coat of the sulphide, which floats off into the discharge tank and is conveyed to the concentrate bins. The tailings from the tube are sent to other tubes, until there is no longer any flotation of sulphides. In a compact form of installation the tubes are arranged in series of two or three each, one above the other. For the successful operation of the process, the pulp must be deslimed before treatment, as otherwise the very fine slowly settling particles of gangue may be floated off with the ore. A plant of 125 tons capacity, employing 100 tubes arranged in sets of four each, as installed at the Adelaide mine, Golconda, Nev., is described[a] as making a successful separation of chalcopyrite with minor quantities of other sulphides from a dense quartzose gangue with spinel and garnet. Experimental tests have also been made upon the copper ore from Ely, Nev., upon copper ore from the Newhouse mine in Utah, and upon the zinc ore at Rico, Colo., the results of which are not available.

"The Elmore vacuum process has been tried experimentally upon various lead-zinc ores in the works of the Empire Zinc Company, at Canon City, Colo., and in the Layton mill, at Salt Lake City, Utah. So far, however, the tests have been successful on but few ores. Tests of zinc ores containing siderite from the Ruth and the Blue Bell mines of British Columbia[b], gave good results with simple acid flotation. Ores from similar mines which did not contain siderite gave poor results.

"Experience has shown that the Australian flotation methods can-

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a. Eng. and Min. Jour., vol. 84, pp. 765-770.
b. Report of the British Columbia Zinc Commission, 1906, pp. 123-128.

not be applied bodily to the lead and zinc ores of this country, but that the delicate balance of the flotation forces must be adjusted to individual ores. Future experimentation will, no doubt, find here a profitable field for such methods."

So far as is known to the writer these methods have not been tried on the ores of the Joplin field and it is doubtful whether they could be made profitable under present conditions. If the price of concentrates should advance materially or if the ore reserve should become depleted, some improved method of separation and concentration will become, not only practicable, but advisable and at present it seems that some form of flotation will be the scheme most likely to be adopted.

METHODS OF SELLING CONCENTRATES.

The concentrates from the mills in the Oklahoma mining camps are sold to buyers from the smelters. Three different plans of determining the price of the zinc concentrates as follows:

(1) A certain price (base price) is allowed for concentrates carrying 60 per cent zinc. Each per cent of excess or of deficiency from 60 per cent adds or subtracts $1.00 per ton. One per cent of iron is usually allowed, and each additional per cent of iron penalizes the ore $1.00 per ton. Each per cent of bitumen gives the same penalty. The moisture is always determined and the percentages of metal determined in the moisture free concentrate.

Example: After the moisture is deducted a carload of concentrates is found to carry 53 per cent of zinc, and 3 per cent of iron. The base price is $40.00 per ton.

60 per cent —53 per cent =7 per cent deficiency.
7 per cent deficiency=$7.00 penalty.
3 per cent of iron=2 per cent more than allowed or $2.00 penalty.
$7.00+$2.00=$9.00 penalty.
$40.00—$9.00=$31.00 price paid for ton of concentrates.

(2) A smelter will contract to take the output of a mine and pay the market price for spelter for 86 per cent of the zinc content. A fixed charge per ton which varies with the nature of the concentrates is deducted from amount per ton as determined by the spelter price.

Example: When spelter is worth 6 cents per pound, ore carrying 54 per cent zinc is worth (86 per cent of 54 per cent of 2000 lbs.)×.06) —$18.
.86×.54×2000×$.06=$55.63.
$55.63—$18.=$37.63 per ton.

(3) The base price 60 per cent concentrates is fixed at $37.50

when the market price of spelter is $.05 per lb. Fluctuation in the price of spelter is allowed for by a change of $8.50 per ton of concentrates for each cent of change in price of spelter per pound. Deduction for zinc content under 60 per cent and penalties for iron and bitumen are assessed in the same way as under the first plans of selling except that 2 per cent of iron is allowed.

Example: Dry concentrates carry 54 per cent of zinc and 3 per cent of iron. The market price of spelter is 6 cents per lb.

Base price of 60 per cent. concentrates when spelter is 5 cents per lb.=$37.50.

Price for 54 per cent concentrates=$31.50. Deduction of $1.00 for iron in excess of 2 per cent leaves $30.50.

Price of spelter is 1 cent in advance of the standard price of 5 cents, hence $8.50 must be added to $20.50, giving $39.00 per ton of concentrates.

The examples given above cannot be compared with each other in ascertaining the relative prices determined by the three methods. The second and third methods are by contract and the known nature of the ore; shipping conditions and other factors may enter into the determination of the fixed amount deducted in the second method, and the establishing of the base price and the ratio of fluctuation in the third method.

In any case the concentrates are sampled in the presence of the buyer and seller or their agents; the sample divided into three portions one of which is assayed by the buyer, one by the seller, and the third reserved to be assayed by an umpire should there be serious discrepancy between the other two assays.

The lead concentrates are usually much purer than the zinc concentrates and are sold at a flat rate per ton, the price depending upon the market price of pig lead.

USES OF LEAD.

Lead is used in many ways both in the metallic state and in compounds. In the metallic form lead is used principally for pipes in plumbing and for surrounding electric wire cables. Sheet lead is used in large quantities for lining sulphuric acid chambers and tank cars for the shipment of the acid. Thin sheet lead, known as tin foil, is used for lining boxes or containers used in packing substances which must be kept from the atmosphere, such as tea and tobacco. Considerable quantities of the metal are used in the manufacture of shot and bullets.

Lead forms an important constituent of several easily fusible alloys, such as type metal, babbitt metal and white metal.

The principal use of lead compounds is as pigments for paint, and about one-half of the lead produced is used for this purpose. White lead is the principal lead pigment and is used to a greater extent than all the others together. Red lead, chrome yellow, orange chrome, and Turners yellow are other lead pigments which have an extensive application.

Lead is used in small proportions in the making of several grades of glass, and some of its compounds, particularly the acetate, sugar of of lead, are used in medicine.

The amounts of lead used for the different uses mentioned above for the year 1907, 1908 and 1909 are shown in the following tables:[17]

Use of Lead in the United States, 1907-1909.

PRODUCTS	1907		1908		1909	
	Quantity	Per cent.	Quantity	Per cent.	Quantity	Per cent.
White lead	short tons		short tons		short tons	
and oxide	115,000	28.8	117,500	40.5	134,138	38.0
Pipe	41,000	12.4	33,800	11.6	52,914	15.2
Sheets	21,500	6.5	16,400	5.7	23,421	6.7
Shot	28,000	8.5	31,600	10.9	36,433	10.4
Other purposes	125,238	37.8	90,700	31.3	104,094	29.7
Total	330,738	100.0	290,000	100.0	351,000	100.0

USES OF ZINC.

The principal use of zinc is in galvanizing sheet iron and wire. By dipping iron into molten zinc, the surface of the iron is covered with film of zinc. When exposed to the weather this becomes covered with a coating of the oxide of zinc which remains on the surface and acts as a protective coating, preventing the further decay of the metal. Sheet zinc is used to some extent for roofing and for stove boards and similar uses. Zinc dust is used in large quantities in dyeing, fire works, manufacture of hydrogen, and as a means of precipitating gold and silver in the cyanide process of extraction of those metals.

Zinc oxide, zinc-lead oxide and lithophone are pigments which are extensively used and which consume large quantities of zinc. They are usually made directly from the ores. Zinc chloride is coming into use as a preservative for wood, especially for railroad ties and for mine timbering. Zinc sulphate and some other compounds are used in medicine.

17. Mineral Resources of the U. S. for 1910, part I, p. 252, from figures in the Engineering and Mining Journal.

CHAPTER II.

THE NORTHEASTERN OKLAHOMA FIELD.

INTRODUCTION.

The Northeastern Oklahoma lead and zinc field is the southwestward continuation of the Joplin district and the general conditions of ore occurrence and of mining are the same as for that area. In view of this fact the general features of the stratigraphy, structure, nature of ores and rocks, shape of ore bodies, and the genesis of the ores are considered in reference to the whole Joplin district. These general considerations are then applied to each of the three mining camps in Oklahoma and the mining development of each camp discussed in some detail.

PHYSIOGRAPHY.

The Northeastern Oklahoma lead and zinc field lies on the extreme southwestern flank of the Ozark Mountains. The surface slopes to the southwest, from a maximum elevation of 1050 feet along the Kansas and Missouri State lines to an elevation of 750 feet at the junction of Spring and Neosho rivers. The region to the east of Spring River (except Jackson Prairie) is hilly, but to the west it grades rapidly into a level prairie underlaid by Cherokee shales.

The drainage is through Spring and Neosho rivers which unite near Wyandotte in the southwestern part of T. 27 N., R. 24 E. to form Grand River.[16] Spring River enters the state from Kansas in sec. 16, T. 29 N., R. 24 E., and flows in a winding course in a general southerly direction to its confluence with Neosho River. For the greater portion of its course it flows on the Boone chert. Owing to the westerly dip of the rocks all the principal tributaries come in from the east. Five Mile Creek, Warren Branch, Flint Branch, and Shawnee Branch rise near or a few miles to the east of the Oklahoma-Missouri State line and flow to the south of west into Spring River.

16. According to a ruling of the United States Board of Geographic Names, the name Neosho is applied to this stream to its confluence with the Arkansas. This ruling, however, conflicts with long established usage and in this report the stream below the confluence of Neosho and Spring River will be called Grand River. In the quotations from the United States Geological Survey, the name Neosho applies to the entire stream.

Neosho River rises in Kansas, crosses the State line in sec. 15, T. 29 N., R. 21 E., and flows southeast in a winding course to its confluence with Spring River. The tributaries from the north flow almost straight south while those on the opposite side of the river have a generally eastward course. Elm Creek, Tar Creek, and Little Elm Creek are the principal tributaries which flow south through the productive lead and zinc areas.

GENERAL GEOLOGY OF THE OZARK UPLIFT.

The Ozark Uplift includes almost all of that part of Missouri lying south of Missouri River, northern Arkansas, the southeastern corner of Kansas, and the portion of Oklahoma lying east of Grand River and north of Arkansas River. The core of the uplift is the St. Francois Mountains, a mass of granite and rhyolite in southeastern Missouri. Lying unconformably on the granite is a great thickness of Cambro-Ordovician limestones and dolomites. The lead of southeastern Missouri and most of the lead and zinc of northern Arkansas are found at this horizon. The Cambro-Ordovician rocks extend into Oklahoma, but the dip is in general to the southwest and these rocks soon pass under younger formations. The surface rocks of most of this area belong to the Mississippian system. The nature of the section of rocks and the formation names vary in different parts of the uplift. In this connection only those rocks outcropping in Oklahoma are considered. The succession of rocks is shown in the generalized geologic section (fig. 5).

Stratigraphy.

Ordovician rocks. The oldest formation exposed in northeastern Oklahoma is the *Burgen sandstone,* a white fine-grained, saccharroidal sandstone which is exposed in the valley of Illinois River in the Tahlequah and Siloam Springs quadrangles. In the Tahlequah quadrangle Taff[17] gives it a thickness of 5 to upwards of 100 feet with the base not exposed. The outcrop widens somewhat to the north in the Siloam Springs quadrangle although only the upper portion of the formation is exposed. At Spavinaw in Spavinaw Creek in the extreme northeastern part of Pryor Creek quadrangle, there is an exposure of white, siliceous, dolomitic rock, which in its sandier portions greatly resembles the Burgen sandstone and which occupies the same stratigraphic position. The Burgen is correlated with the Saccharroidal sandstone, of the Arkansas Geological Survey, which lies immediately above the Yellville limestone. Taff reports the Burgen as nonfossiliferous but the writer has observed a few very poorly preserved *Orthoceras* on the surface of

17. Taff, J. A., Tahlequah folio (No. 122), Geol. Atlas U. S, U. S. Geol. Survey, 1905, p. 2.

blocks near the Tahlequah-Siloam Springs quadrangle line near Illinois River.

Above the Burgen sandstone is a series of greenish shales with some brown sandstone and some limestone known as the Tyner formation. Along Illinois River northeast of Tahlequah the top of the formation is

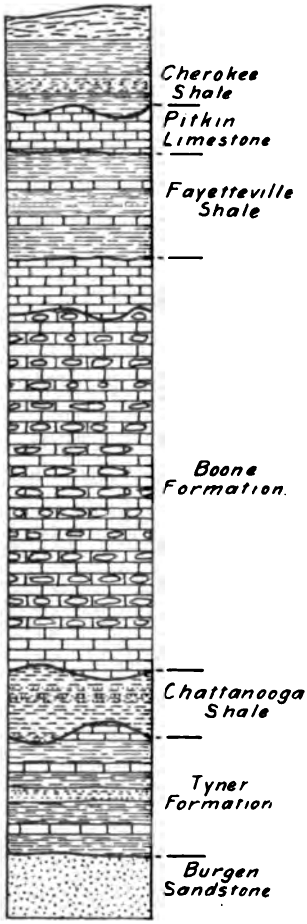

Fig. 5. Generalized geologic section for Northeastern Oklahoma.

a limestone of variable thickness (a few inches to 20 feet) containing fossils of Black River age. Along Barren Fork River only the top of the formation is exposed and it consists of thin shales and sandstones containing fossils of Lorraine age. This horizon is therefore believed to be above that of the limestone at the top of the formation along

Illinois River. Since the entire Silurian is unrepresented in this locality, the upper beds were probably removed by erosion during Silurian times, before the deposition of the Devonian black shale which succeeds it. At Spavinaw a single exposure of a green shale was noted below the black shale and a "copper-stained shale" is reported from the same horizon by the driller of a deep well near Vinita. This would indicate that the Tyner formation is persistent to the northeast under the younger rocks.

Silurian rocks. The St. Clair marble of Silurian age outcrops in the southeastern part of the Tahlequah quadrangle where it is brought to the surface by faulting. Silurian rocks are not represented in the northern part of the Tahlequah nor in the Siloam Springs, Pryor Creek, or Wyandotte quadrangles.

Devonian rocks. The Devonian system is represented by the Chattanooga shale which outcrops in stream valleys south of Cowskin River. This is a black, bituminous, slaty shale of very uniform texture and composition and of great areal extent, the black shales at this same horizon in Arkansas, Tennessee, Kentucky, Indiana, and Ohio being continuous and so uniform in character as to be indistinguishable. Since it is limited both above and below by unconformities the thickness is very irregular. Siebenthal[18] gives the thickness in different localities as follows:

"* * * In the east bluff of Neosho [Grand] River, 3 miles above the mouth of Cowskin River, the thickness is 26 feet; on Buffalo Creek it is 20 feet, at Southwest City 50 feet, at the mouth of Honey Creek 83 feet, and at Spavinaw 90 feet. On Spring Creek 25 feet, not the full thickness, was noted." Taff reports the thickness in the northern part of the Tahlequah quadrangle as 40 feet, and in the southern part as 20 feet.

In the bluff of Illinois River near the southern line of the Siloam Springs quadrangle the thickness is 60 feet and at the confluence of Flint Creek with Illinois River it is between 30 and 40 feet disregarding the Sylamore member. The Chattanooga is also reported in deep wells at Grove and at Vinita. The Sylamore sandstone member lies at the base of the Chattanooga shale. It is exposed in Arkansas and in the southeastern part of the Tahlequah quadrangle but is absent or very thin in the northwest part of the Tahlequah and southwest part of the Siloam Springs quadrangle and in the Spavinaw region. Along Flint Creek in the central part of the Siloam Springs quadrangle it is 15 to 20 feet thick.

Mississippian rocks. The rocks of Mississippian age include the Boone chert, the Fayetteville shale with its Wedington sandstone mem-

18. Siebenthal, C. E., Bull. U. S. Geol. Survey, No. 340, 1907, p. 189.

ber, the Batesville formation and the Pitkin limestone. The Boone chert is of Burlington-Keokuk age and the other formations are correlated with the Chester group.

The Boone chert is the thickest formation of the region and outcrops over a far greater area than all the other formations combined. In Oklahoma its outcrop includes practically all of Delaware and Adair counties, the southern half of Ottawa County, the southeastern corner of Craig County, the eastern half of Mayes County, and all except the southwestern one-fourth of Cherokee County. It also occupies a large area in northeastern Arkansas and practically all of the Joplin district in southwestern Missouri and southeastern Kansas.

The nature of the formation varies considerably in different parts of its outcrop. In the southern part of its outcrop in Oklahoma, in the Tahlequah quadrangle (Adair and eastern Cherokee counties) Taff[19] describes it as follows:

"The rocks of the Boone formation consist of interestratified chert and cherty limestone. At the base there are in places thin limestones free from chert, while at other localities the chert rests on the Chattanooga shale without intervening limestone beds. The limestone beds at the bottom, being distinct in lithologic character from the body of the formation and variable in thickness, are properly characterized as a member of the formation.

"The base of the Boone formation is exposed in twelve localities, and in four of these limestone was found beneath the chert. Of the known occurrences of limestone beneath the chert two were found bordering the small areas of the Chattanooga shale in Barren Fork Valley south of Westville. In the smaller area in the west side of sec. 34, T. 17 N., R. 26 E., the limestone is about 5 feet thick. At the other locality, 3 miles down the stream, it is 10 to 15 feet thick. At these places it consists of fine-textured and dense, white to pinkish, even-bedded limestone. Light-colored crinoidal limestone beds 10 to 15 feet thick occur at the base of the Boone formation in the south bank of Barren Fork at the road crossing in the NW.¼ sec. 13, T. 17 N., R. 23 E. No fossils were collected from this limestone at the three localities named, but its position in the formation and its lithologic character strongly indicate that it should be correlated with the basal St. Joe member of the Boone formation exposed in the northern part of the Fayetteville quadrangle and farther east in northern Arkansas.

"A fourth locality of the basal limestone member of the Boone formation is in a small valley leading into Illinois River in sec. 36, T. 18 N., R. 22 E., very near the north border of the quadrangle. Here the beds consist of dull blue and earthy fossiliferous limestone in the lower part,

19. Taff, J. A., Tahlequah folio (No. 122), U. S. Geol. Survey, 1905, p. 2.

followed above by thicker and harder limestone beds, the thickness of the whole being 6 feet. These beds belong stratigraphically below the lighter-colored crinoidal limestones, both being locally developed. They contain the following fossils, together with a number of undetermined and mostly undescribed species, all indicating Kinderhook age:

Leptaena rhomboidalis Wilckens.
Productella concentrica Hall.
Spirifer cf. peculiaris Shumard.

"The lighter-colored, often pink, and generally crystalline crinoidal limestone, together with the lower part of the cherty limestone, overlying it, contains a Burlington fauna. The common fossils in this division include the following species:

Schizoblastus sayi Shumard.
Platycrinus and fragments of other crinoids.
Spirifer grimesi Hall.
Syringothyris sp.
Productus cf. semireticulatus.

"The middle member constitutes almost the whole of the Boone formation as exposed in this quadrangle, and is made up essentially of calcareous chert or flint with variable bands or beds of limestone.

"Fresh exposures occur in but few places and these are in steep bluffs and cliffs where the larger streams meander against the sides of their valleys, or more rarely in the beds of the smaller streams in their middle or lower courses where the grades are sufficiently steep and the volume of water great enough to induce active erosion. The chert element predominates so greatly over the limestone in abundance, and is so resistant to the effects of erosion, that almost the entire surface rock consists of angular chert bowlders and fragments.

"The cherts in the upper part of the formation are locally very fossiliferous. The following list includes the species most commonly found, and their association is decidedly indicative of Keokuk age:

Amplexus fragilis White and St. John.
Glyptopora keyserlingi Prout.
Fenestella multispinosa Ulrich.
Polypora maccoyana Ulrich.
Hemitrypa proutana Ulrich.
Pinnatopora striata Ulrich.
Spirifer logani Hall.
Reticularia pseudolineata Hall.
Productus setigerus Hall.
Orthotetes keokuk Hall.
Capulus equilaterus Hall.

"The limestone overlying the chert was believed to be a part of the

Boone formation at the time the Tahlequah quadrangle was surveyed and is included with it in the mapping. Later studies of this limestone made in connection with the survey of the Muskogee and Winslow quadrangles, west and east of the Tahlequah, have shown that locally, at least, a thin bed of black shale occurs between this limestone and the Boone chert. An abundant fauna, also, which has been collected from it, shows that it is higher geologically than the Boone and should be classed with the Fayetteville formation.

"The thickness of the Boone formation is variable. It ranges from a minimum of 100 feet to a maximum approximating 300 feet. Except in a few localities the top and base are separated in outcrop by several miles, and the rocks are so concealed by surface chert debris that the determination of thickness are at best only approximate."

In the Siloam Springs quadrangle, (northern Adair, northeastern Cherokee, and southern Delaware counties) the base of the formation is exposed for a considerable distance along Illinois River, especially along the west side (fig. 2). Good exposures of the base are also had along Flint Creek and along Spavinaw Creek from its confluence with Cloud Creek to below Spavinaw post office in northeastern Mayes County. In this region the lowest portion is of limestone which rests on the uneven surface of the Chattanooga shale. Immediately above the shale on Illinois is a variable thickness of shaly thin-bedded bluish and greenish fossiliferous limestone. The thickness of this horizon varies widely within short distances. In Eagle Bluff on the west bank of Illinois River in northern Cherokee County, (southwestern part of the Siloam Springs quadrangle) the bed thickens from 15 feet to 60 feet and thins again to 12 feet in a distance of less than one-half mile. Some fossils from this horizon indicate that these beds are the equivalent of the Fern Glen formation at the top of the Kinderhook. This fossiliferous limestone is absent at Spavinaw or is represented by about 6 inches of greenish shale. Above the basal shaly limestone bed is a hard, pinkish, crinoidal limestone from 6 to 12 feet in thickness. This limestone is a good horizon marker as it is often exposed and breaks off into large blocks.

Above the crinoidal limestone is a succession of limestones and cherts, usually in layers 6 to 10 inches thick, which continues nearly to the top of the formation.

Thicker limestones occur at the top of the formation which are well exposed near Grove in northern Delaware County where one of them has been used for burning into lime.

In the Joplin district of Missouri and Kansas, the Chattanooga shale seems to be absent and the Boone rests upon the non-persistent Hannibal shale.[20] Two members are recognized, the Short Creek

20. Siebenthal, C. E., Joplin District folio (No. 148), Geol. Atlas U. S., U. S. Geol. Survey, 1907.

oolite member 8 feet thick which lies about 100 feet below the top of the formation and the Grand Falls chert, 35 to 55 feet thick which occurs 100 feet below the Short Creek oolite. This chert represents the lowest horizon of commercial lead and zinc deposits in southwest Missouri.

In the paper on the Mineral Resources of Northeastern Oklahoma,[21] Siebenthal gives the following description of the Boone:

"The Boone formation is made up of an alternating series of limestones and cherts, approximately 300 to 350 feet in thickness where fully developed. It forms the surface rock over by far the largest part of the area of Mississippian rocks. At the base of the formation there is always present a limestone member, consisting at the top of a heavy ledge of coarsely crystalline encrinital limestone, or marble, which is usually 10 to 15 feet in thickness. This bed is separated by several feet of shaly limestone from a lower ledge of flaggy limestone, locally rather cherty and in many places irregularly bedded, which lies upon the Chattanooga shale. The upper ledge usually outcrops as a smooth, wall-like bluff, from which large blocks, the full thickness of the ledge, break away. It has been correlated with the St. Joe limestone member in the Tahlequah and Fayetteville folios. This limestone is normally overlain by a series of dark limestones and cherts from 50 to 80 feet in thickness. Above these, to the top of the formation, are lighter colored cherts and limestones, with one or more massive ledges of limestone 10 to 20 feet in thickness. The Short Creek oolite member, noted in the Joplin district, is found in the east half of the Wyandotte quadrangle wherever its horizon is exposed, though west of Spring and Neosho rivers it usually pinches out or loses its oolite character."

The rocks of Chester age outcrop in a belt of variable width between the Boone outcrop and that of the Pennsylvanian rocks. In the Tahlequah quadrangle (in southern Adair and southeastern Cherokee counties) the rocks consist of the Fayetteville shale with the Wedington sandstone member near the top, and the Pitkin limestone. The Wedington sandstone member is about 20 feet thick and caps the hills in the vicinity of Westville. To the west the Wedington thins out and is not represented in the Muskogee quadrangle (in western Cherokee, northeastern Muskogee, and southeastern Wagoner counties). In this vicinity there are local limestone lenses and thin limestone near the top and the bottom of the formation which are continuous over considerable areas.

In the Wyandotte quadrangle (western Ottawa County) Siebenthal[22] gives the Batesville, Fayetteville (with its Wedington member) and Pitkin formations as members of the Chester group. The Batesville sandstone in Arkansas lies between the Boone and the Fayetteville but thins

21. Bull. U. S. Geol. Survey, No. 340, 1907, p. 190.
22. Op. Cit.

rapidly to the west and does not appear in the Tahlequah or Muskogee quadrangles. In the Joplin folio Siebenthal gives the Carterville formation as occupying the horizon of the Chester group in the Joplin district so the formation which he calls Batesville in the Wyandotte quadrangle is evidently not continuous with the Batesville in Arkansas. The same thing applies to the Wedington sandstone member of the Fayetteville shale for as has been noticed in the preceding paragraph it does not appear in the Muskogee quadrangle and the whole Batesville-Fayetteville interval is represented by the Carterville formation in southwestern Missouri.

In the portion of the Pryor quadrangle east of Grand River (eastern Mayes and northwestern Cherokee counties) is a considerable thickness of limestone which occurs immediately above the Boone formation. This is probably the limestone which was included in the base of the Fayetteville by Taff. In the Pryor quadrangle, however, it has sufficient thickness and outcrops over sufficient area to be ranked as a distinct formation. Two limestone horizons occur in the Fayetteville but they are distinct from the one just mentioned.

The Pitkin limestone is described by Taff[23] in the Muscogee folio as follows:

"The Pitkin limestone consists of light-blue to brown, granular, earthy, slightly oolitic strata interbedded with fine-textured massive layers. The granular and oolitic types of rock are the more common and may be said generally to characterize the formation. The thickness of beds is variable, ranging from thin platy strata to beds 1 or 2 feet thick. The thinner strata are usually more argillaceous, and thin shale layers not uncommonly separate them.

"The Pitkin limestone is considered to be the top of the Mississippian series of the Carboniferous. The fossils listed as from the upper limestone of the Fayetteville formation are equally characteristic of the Pitkin.

"In thickness the Pitkin limestone in the Muscogee quadrangle varies but little from 50 feet, such slight changes as probably occur being due to erosion of its upper beds prior to the deposition of the overlying formation. Where the shaly bed is concealed the boundary between the Pitkin and Morrow formations is difficult to determine without a careful study of the fossils in the limestones both above and below the contact. In places shale, and in other localities sandy shale as well, may be found above the Pitkin limestone. This represents the Hale sandstone member of the Morrow formation, which is well developed in the Tahlequah quadrangle and farther east in Arkansas.

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22. Muscogee folio (No. 132), Geol. Atlas, U. S., U. S. Geol. Survey, 1905.

"The Pitkin limestone crops out generally at the bases of hills and in steep slopes, bluffs, and escarpments of the higher Morrow and Winslow formations, the talus from which frequently conceals the contact. Toward the east, beyond the Tahlequah quadrangle, the Pitkin limestone occurs in isolated areas and crops out along the northern foothills of the Boston Mountains in northwestern Arkansas. Typical exposures occur in the north slopes of the Boston Mountains near Pitkin, on the St. Louis and San Francisco Railroad, from which place the name of the limestone has been taken. The formation was described by Dr. F. W. Simonds (Arkansas Geol. Survey, vol. 4, 1889), by whom it was called the Archimedes limestone. Archimedes, the generic name of one of the characteristic fossils, not being an appropriate designation for a formation, a name of geographic significance has been substituted."

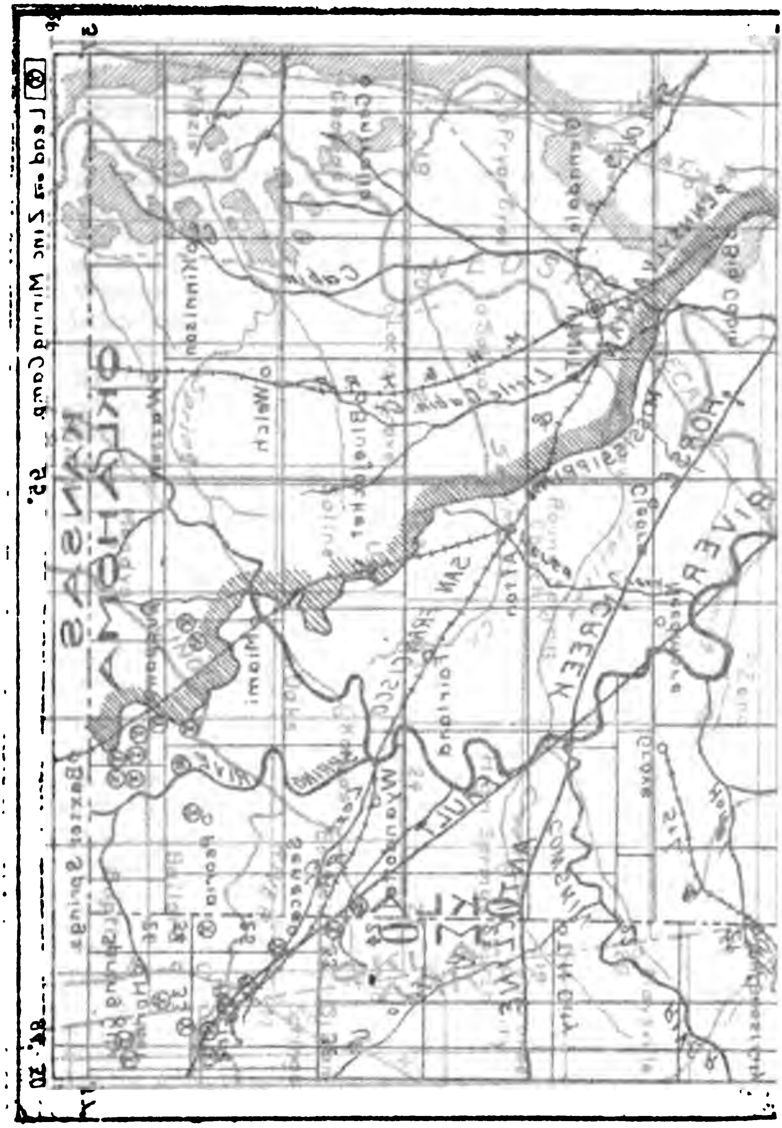
Siebenthal mentions the Pitkin as outcropping in the Wyandotte quadrangle but gives no description of it in the paper previously cited. In the southeastern corner of the Vinita quadrangle Ohern reports a limestone which is much thinner and more argillaceous than the Pitkin. but which is correlated with it on account of its position and the preliminary paleontological studies which have been made. A limestone which has about the stratigraphic position of the Pitkin outcrops near the top of the hills in the vicinity east of Pryor Creek but detailed work in this quadrangle is necessary before the horizons in the north can be definitely correlated with the section as exposed in the Muscogee quadrangle.

Pennsylvanian rocks. In the southern part of the area the Morrow and Winslow formations are exposed. To the north these formations cannot be distinguished. There are three possible causes for their disappearance: (1) they may actually pinch out entirely; (2) they may thin out and merge with the Cherokee (Vinita of Ohern)[24] shales; (3) the strike may continue to the northwest and pass under the Cherokee shales, i. e., the Cherokee shales may be uncomformable by overlap on the older Pennsylvanian sediments. Siebenthal seems to hold to the last conclusion since on page 191 of U. S. G. S. Bulletin No. 340 he says: "The continuation of the sandstone and the shales of the Winslow beneath the overlapping formations would naturally be sought in the line of strike of the present outcrop of these rocks. Because of the probable curvature of the shore line of the uplift, the buried extension of the Winslow should be expected somewhere between Chelsea, Nowata, and Coffeyville, Kansas."

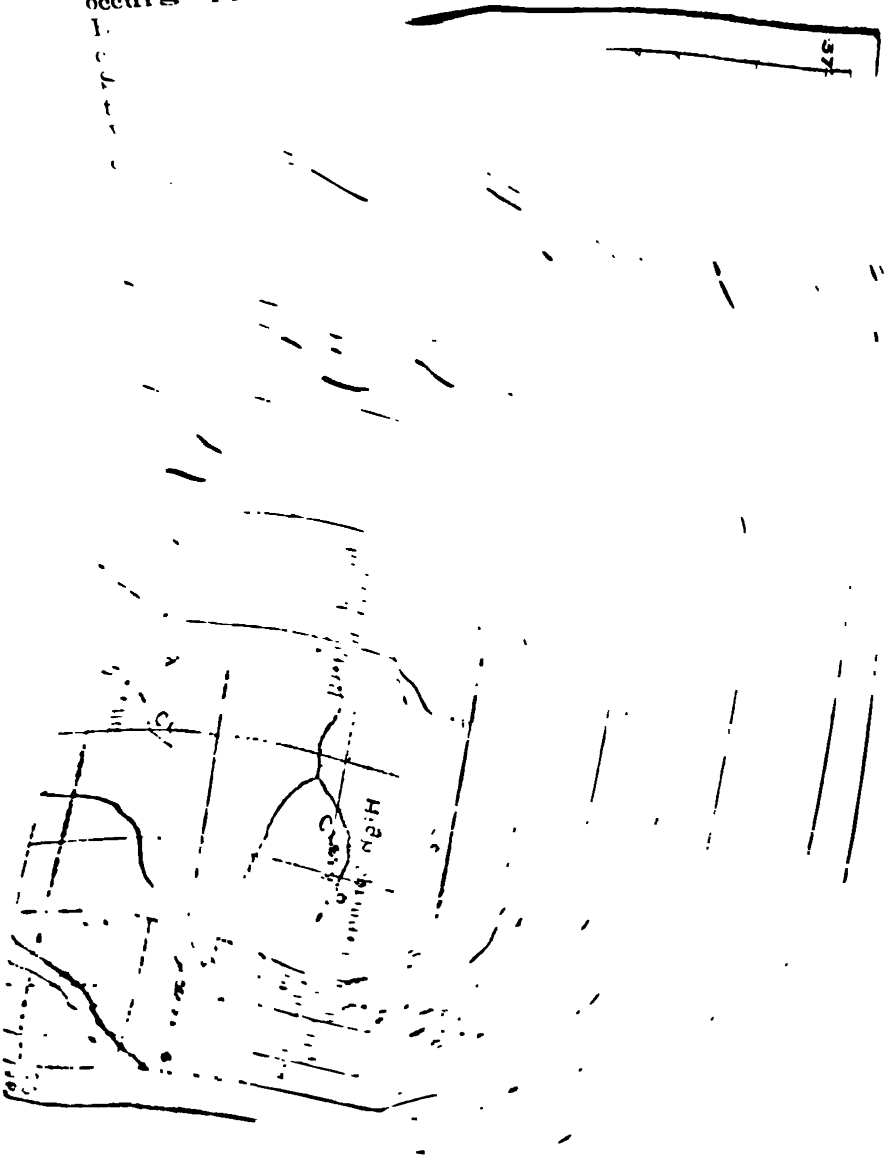
Considerable field work is necessary to settle this question. The important point in connection with this report is that the westward trend of the overlying formations places the beginning of the warping of this portion of the Ozark Uplift near the end of Winslow time.

24. Univ. of Oklahoma Research Bull. No. 4.

Structure.



"The Pitkin limestone crops out generally at the bases of hills and in steep slopes, bluffs, and escarpments of the higher ... low formations, the talu... Toward the east ... occurs in ...



Structure.

The entire area under discussion is the southwestward extension of the Ozark Uplift. The dip is usually southwest at low angles. Around the southern portion of the area of Mississippian rocks in Oklahoma the dip is to the south and southeast.

he chief structural features of the region have been described by hal in the work previously cited and his discussion is given in full. g. 6.)

s has been remarked in the section on the correlation of the e formation, the discordance of strike of the Winslow, Savanna, ggy with the Fort Scott and overlying formations shows a warp- he west end of the Ozark uplift somewhere in the period between e of the Winslow deposition and the early part of the Cherokee. thern portion was elevated, crowding the shore line far to the st, while the northern portion was depressed, allowing the sea nce to the east. The northeast-southwest orientation of the ie was well established early in Cherokee time, and this relative was maintained through the remainder of the Pennsylvanian, the formations of this age outcropping in this region in lines parallel ort Scott limestone, with gentle northwesterly dips ranging from er mile in the northern portion of the area to 50 feet in the south- ion.

FOLDING AND FAULTING.

ie folds and faults of the area are so closely related that their scussion seems preferable.

he axis of that part of the Ozark uplift included in Oklahoma from northeast to southwest, and the margin of the uplift is ser- y an interesting system of parallel normal faults, which Taff has d in the Tahlequah and Muscogee folios. These faults trend l to the axis of the uplift, and at either end usually develop into ines or asymmetric anticlines and gradually die out. An in- n of the map will show the close relation of the minor drainage to ults. Northwest of Tahlequah the parallelism of the faults is not nounced and the system is somewhat complicated by intersecting faults. These faults are of post-Winslow age, but no relation to formations can be established.

'Extending southward from Locust Grove is a prominent fault with ownthrow to the west, which brings the Chester down to a level 100 50 feet lower than the top of the Boone chert hills immediately east.

"The next prominent structural feature toward the north is the eca fault, which extends from a point midway between Choteau and

Pryor Creek to a point several miles northeast of Spurgeon, beyond the limits of the area shown on the accompanying map, having an almost due northeast course parallel to the main axis of the uplift and roughly parallel to its northwest margin. This fault is double and in places multiple, letting down a long, narrow block of Boone, Chester, and overlying rocks into the Boone formation. In addition to the downthrown block, the strata for some distance, in places for a mile or two on either side, dip toward the fault. This combination has had a strong influence on the drainage, as may be seen from the map. From Seneca toward the northeast the fault closely follows the valley of Lost Creek. South of Seneca it crosses the divide to Sycamore Creek and follows down the valley to Neosho River. From the mouth of Sycamore Creek the fault cuts across the various meanders of Neosho River to a point just above the mouth of Spavinaw Creek. Southwest of this point it traverses the flat upland to and beyond Pryor Creek. Near the Neosho, where the rocks on either side are the cherty limestones of the Boone formation, it is easy to trace the down-dropped strip of Chester consisting of limestone and sandstone. Farther to the southwest, where the Chester formations become the prevailing surface rocks, the fault is difficult to follow. In the Pennsylvanian area it is quite impossible to trace the fault, but whether this is due to its absence, to the uniformity of the rocks, or to the concealment of the faulted Winslow by the overlapping Cherokee was not determined. If the last explanation is correct, as is quite likely, the fault is post-Winslow and pre-Cherokee and probably of the same age as the parallel faults of the Tahlequah-Muskogee region and as the warping to which all the faults are with little doubt genetically related. Owing to the fact that the amount of throw is variable within short distances along the fault and to the further fact that the fault line coincides so closely with the drainage lines, the Chester formations are preserved but here and there along the fault.

"The intersections of this fault line with the meanders of Neosho (Grand) River afford many fine cross sections of the faulted area. The width of the down-dropped block ranges from less than 200 feet to more than 1,500 feet. The fault ranges in character from a simple pair of opposed breaks with the down-thrown block between them, and with the strata of the wall rock on either side dipping more or less steeply toward the faulted block, to a sort of faulted syncline, the limbs of which are made up of distributive faults with the cummulative downthrow toward the axis of the syncline. The best view of the latter phase is shown in the west bluff of the Neosho opposite the mouth of Cowskin River, where the south limb dips from 2° to 5° N., the angle increasing toward the axis, and shows four distinct dislocations, one being opposed to the other three, but leaving a resultant throw of 14 feet to the north. On the north side there is a faulted zone 55 feet wide in which there is an upthrow of 18 feet, but this is more than counterbalanced by three small

faults and one with a throw of 22 feet to the south, and by the southerly dip of 2° some distance from the fault and of 11° adjacent to the fault.

"The amount of displacement on either side of the block varies from place to place. In the west bluff of Neosho River 2 miles below the mouth of Horse Creek it is more than 90 feet. At the Bedker mines, south of Seneca, it is from 100 feet to 140 feet. Between Seneca and Spurgeon it must be as much as 100 feet in many places, for it serves to bring the Chester formation down to the level of the valley, though the Boone forms the top of the hills on either side.

"The Horse Creek anticline is an asymmetric fold which starts at a point on Cabin Creek, 5 miles southeast of Big Cabin station and trends east northeastward by Cleora to the mouth of Cowskin River, where it intersects the Seneca fault. East of this point it swings a little more eastward to the vicinity of Tiff City, where it trends nearly due east for 10 miles and farther east gradually dies out. The anticline has a gently sloping northern limb and a steeper southern limb. To the south of the anticline and parallel to it is a long, low synclinal trough beyond which the strata rise again to the south, with a gentle incline. The average dip of the northern limb of the anticline is about 2°; the dip of the southern limb ranges from 5° to 18°. West of Neosho River the fold expresses itself topographically in an abrupt fault-like escarpment to the south and a low upland slope to the north. East of the Neosho the anticline is cut through on either side by many short, steep hollows, and forms the greatly dissected highland known as the Seneca Hills. In places, notably where the fold is cut through by Neosho River, the rocks lie nearly flat, but where it is crossed by Buffalo Creek and Horse Creek the dip is about 5° SE. About 2 miles west of Horse Creek Gap the dip is 18° SE. For the most part the dip of the southern limb is concealed by debris washed down from the steep slope, and can be made out only in exceptional places. It is entirely possible that for short distances along the axis west of Horse Creek the anticline may break down into small faults. Though cut across in several places by streams, this fold is nowhere breached parallel to the axis, a fact due doubtless to its monoclinal nature."

The faults and folds in the southwestern margin of the uplift which are mentioned in the first paragraph probably extend for a considerable distance to the east, although it is not possible to trace them across the hills which are covered to a depth of several feet with loose, residual Boone chert. Folds were noticed along the Illinois River in the southern part of the Siloam Springs quadrangle (northeastern Cherokee County) whose axes had approximately the same direction as those around the margin of the Mississippian rocks to the southwest. One fault was observed which brings the portion of the Boone chert above the crinoidal member near the base into contact with the Chattanooga shale. Both

the folding and the fault can be distinguished only in the bluffs of the river and it is impossible to see any evidence of them on the timbered Boone chert hills.

The effects of the pre-Cherokee underground solution which are so closely related to the lead and zinc deposits in the whole Joplin district occur only in a small area in the extreme northeast corner of the State. This subject of underground solution and its relation to the lead and zinc ore deposits is considered more fully in connection with the origin of the ores.

Review of the Geological History.

The area of the Ozark uplift was probably a land mass during the greater part of pre-Cambrian and during Lower Cambrain time. The igneous rocks were deeply eroded in these periods as is shown by the extremely uneven floor upon which the Cambrian sediments rest, although the irregularities have probably been emphasized by post-Cambrian disturbances.[25]

During the Middle Cambrian the entire area was submerged and during this epoch and Upper Cambrian (Ozarkian of Ulrich)times a great thickness of sandstones, limestones and dolomites was deposited. In southeastern Missouri the Upper Cambrian or Ozarkian is separated from the basal Ordovician sandstone (St. Peters) by an unconformity but in northern Arkansas there is no break between the two systems and the sedimentation of limestones and dolomites (Yellville formation) seems to have been continuous. The Yellville formation extends westward under the younger rocks into Oklahoma so that in this region, also, the deposition was not interrupted between Cambrian and Ordovician times, and was continuous to the end of the time of deposition of the Burgen sandstone. There may have been periods of non-deposition during Upper Ordovician time since there are pronounced faunal breaks in the Tyner formation but there are no unconformities which indicate long periods of erosion.

The Silurian is represented by the St. Clair limestone in Arkansas and in the southern part of the Oklahoma area, but farther north and west there was no deposition and there was at least local emergence, evidenced by the absence locally of the upper beds of the Tyner and uneven lower surface of the Chattanooga shale.

The region probably remained near the surface or above the water during lower and middle Devonian times since there are no deposits representing these periods, and there is no evidence of sufficient erosion to have removed them, but was resubmerged during the upper Devonian,

25. Missouri Bureau of Geol. & Mines, vol. IX, part I, pp. 17-18.

and the Chattanooga shale was deposited. Another emergence followed and the upper surface of the Chattanooga was eroded.

About the end of Kinderhook times the Mississippian sea advanced and the Boone formation was deposited. The deposition of the Boone probably occupied all of Burlington-Keokuk times. The Boone was probably deposited far to the east of its present outcrop, the outcrop having been carried toward the margin of the uplift by erosion in subsequent times. After the deposition of the Boone, there was a period of emergence. The Warsaw, Salem, St. Louis and lower part of the Chester formations are absent and were probably not deposited.

After the deposition of the Pitkin there was a slight emergence and a resubmergence during which the Morrow and the Winslow formations of Pennsylvanian age were deposited to the southwest. This submergence advanced to the north and east and gradually covered the country to the north and east to a considerable distance. In this sea the Cherokee shales were laid down on the unevenly eroded surface of the Boone chert. The erosion interval in latest Mississippian times and early Pennsylvanian times is of supreme importance in the deposition of the lead and zinc ores of the Ozark uplift. This subject is discussed by Buckley and Buehler in their report on the Granby area[26] as follows:

"At the close of the Mississippian, there was an erosion interval of considerable duration. During this period the upper beds were removed and the land deeply trenched by running water. The underground waters flowing along joints took the limestone into solution, producing caves, caverns and sink holes.

"During this period there was also a process of concentration, recrystallization and silicification in progress. The beds of limestone became more completely crystalline; the original flint nodules were enlarged through the replacement of the limestone by silica; and the limestone beds were silicified. Perhaps, near the surface, during the latter part of this erosion interval, the flint may have been partly decomposed forming cellular chert (flint).

"Just the order in which these changes occurred and the position of the altered beds with respect to the surface, are not known. We only know that the limestone was saturated with mineralizing solutions, carrying chiefly calcium carbonate and silica; and that zinc and lead salts were not deposited, and therefore probably not carried in solution.

"The great thickness of the limestone deposits of the Mississippian, and the enormous deposits of coal formed during the Pennsylvanian, have lead some to believe that the atmosphere during the post-Mississippian erosion interval was heavily charged with carbon dioxide. If

26. Missouri Bureau of Geol. & Mines, vol. IV. 2nd series, pp. 31-32.

this be true, the water falling upon the land must have been more heavily charged with carbon dioxide than at present. Such a condition provides an easy explanation for the extensive solution of the limestone to a depth beyond the present zone of cementation. Solution and silicification appear to have been much greater prior to the Pennsylvanian than since, although the recent silicification represented by the black flint is very prominent.

"The Mississippian limestone was probably subjected to a longer period of erosion, prior to Pennsylvanian times, than it has been since erosion has removed the Pennsylvanian.

"It may be well to repeat that there is no evidence that either lead, zinc, or dolomite in any form, were deposited during the Mississippian period or the post-Mississippian erosion interval; that there is evidence of deposition and solution of silica; and that the limestone was very generally re-crystallized and removed in solution where it came within the belt of weathering.

"The close of this period left the land rough and hilly, very much as it is today. The upper beds of limestone had either been removed or altered into a rough, porous or dense, nodular chert. The hillsides were covered to an unknown depth with broken fragments of flint forming a talus. Within the hills, back from and beneath the talus, the limestone was dissolved for some distance, causing the beds of flint to drop down and dip toward the valleys, as shown in the accompanying illustration (fig. 7). The thin beds of flint were broken into small fragments, while the heavier beds were tilted from the limestone toward the valley. This is the condition in which we suppose the land to have been at the time the Pennsylvanian period was inaugurated."

As has been said the submergence in Cherokee times extended far to the eastward. Isolated patches of Cherokee shale and sandstone are found over the entire southwestern Missouri lead and zinc field. The length of the period of submergence is not known but if it was prolonged beyond Pennsylvanian times the later sediments have been entirely removed by erosion unless some deposits of uncertain age to the north of the Ozark uplift should prove to be Permian or Triassic. There is no trace of Cretaceous sediments so it is probable that the final uplift began before Cretaceous times although the rocks may have been deposited and removed by erosion.

Haworth[27] decides that the amount of erosion accomplished by the streams is no more than might be produced by them since the middle of the later part of Tertiary times. The absence of great structural features indicates that the uplift took place quietly and probably occupied a great length of time.

27. Univ. Geol. Surv. of Kans., vol. 8, 1908, p. 58.

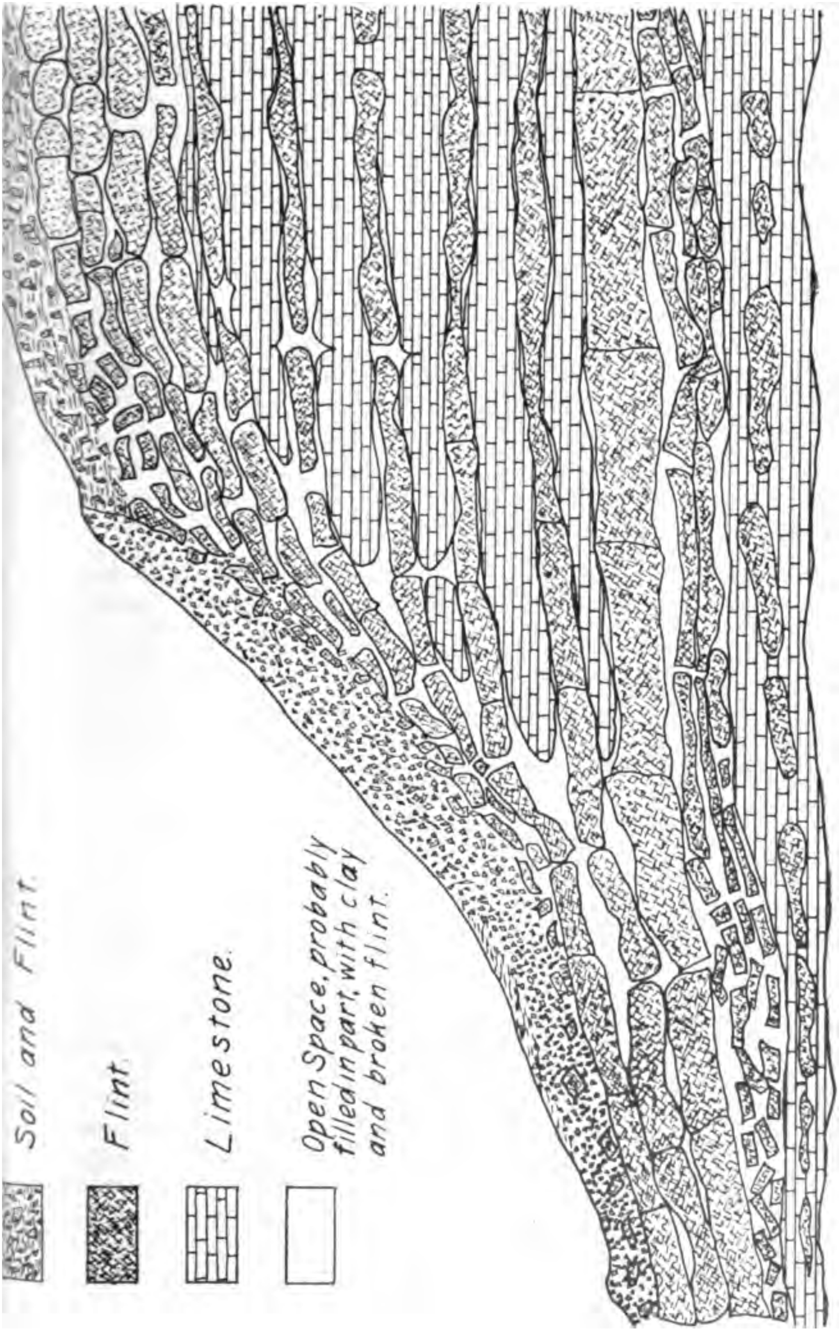


Fig. 7. Ideal illustration of the Mississippian near the surface just prior to the deposition of the Pennsylvanian (after Mo. Geol. Survey).

NATURE OF THE ORES.

The ores of the entire Joplin district fall into two classes; the oxidized ores, or those found above the level of the ground water in the zone of surface weathering, and the unoxided or sulphide ores found in the deeper workings.

The oxidized ores are zinc carbonate, smithsonite or "dry bone"; zinc silicate, calamine, or "silicate"; lead carbonate, cerrussite or "dry bone" and subordinate amounts of lead sulphate, anglesite. These ores have been produced by the oxidizing action of the surface weathering agencies on the sulphides. Considerable galena or "lead" is found near the surface usually associated with calamine or anglesite. It may be regarded as being the residuum of the sulphide ores which has not been acted upon by the oxidizing agencies.

Zinc carbonate, smithsonite, which is called "dry bone" in the northern Mississippian fields is of small importance in the Joplin district. It is not present in commercial quantities in the northeastern Oklahoma area.

Zinc silicate, calamine, or "silicate" is produced by the oxidation of zinc sulphide. It occurs in Oklahoma usually in irregular forms which are finely crystalline. The color is a gray on the outer surface and usually vitreous on freshly broken surfaces. Some mammillary and stalactitic forms occur, and also small rounded grains known as fish egg silicate. This ore has been produced in considerable quantities in the Peoria camp and to some extent in the Quapaw camp. It does not occur at Miami.

Lead carbonate, cerussite, is usually known in the Joplin district as "dry bone". It occurs at Peoria in rather small amounts usually as flat plates showing little or no crystalization. It also occurs as a coating on galena crystals. No cerussite was observed at Miami.

Lead sulphate, anglesite, occurs as white powder coating galena. It is also associated with lead carbonate. By itself it cannot be considered as an ore of lead as it occurs in too small quantities.

Below the zone of oxidation, i. e. below the level of ground water, the lead and zinc ores are in the form of the sulphides. Lead sulphide, galena or "lead" as it is called by the miners, is a mineral of a gray color characterized by its cubical cleavage. Zinc sulphide, sphalerite, or blende is usually called "jack" by the miners although in some districts calamine is called jack. Sphalerite when pure is almost colorless but usually contains sufficient iron to darken the color to that of resin and sometimes almost to a black. The lustre is resinous. The ordinary form of crystallization is tetrahedral but the crystal form is not distinguishable in large masses of the material. Small crystals of spalerite often show

the tetrahedral form. Large pieces of sphalerite cleave easily into approximately cubical pieces.

In the majority of the mines in the Joplin district sphalerite and galena are mingled so that small specimens of ore contain both minerals. The proportions of the two vary widely and irregularly. As a general rule the proportion of lead decreases with depth but locally the reverse is true.

ASSOCIATED ROCKS AND MINERALS.

The principal rocks and minerals associated with the lead and zinc ores in the Joplin district are as follows: Chert, or flint or limestone, sandstone (in the Miami camp), shale, clay, bitumen, pyrite, calcite, dolomite, barite, chalcopyrite, and greenockite.

Chert or Flint. Buckley and Buehler[28] recognize three generations of chert in the Joplin district. First a white, primary variety which occurs as layers between the limestones of the Boone formation and as lenses and nodules through the limestone. This chert is devoid of fossils, is dense and compact, breaks with a sharp splintery and sometimes conchoidal fracture. This rock makes a considerable portion of the Boone formation and owing to the greater solubility of the limestone remains as a covering of residual chert over the hills of the entire region. The chert weathers locally to a soft porous rock known as tripoli.

A second generation of flint is a white, gray, or blue variety containing fossils, and thought to be a replacement of the limestone. The third is a black flint which contains no fossils, and which occurs as a matrix in which are imbedded angular pieces of the primary flint (fig. 8). It is considered as having been formed by the hardening of siliceous mud which formed contemporaneously with the deposition of the ores.

The first and second generations of flint contain no lead or zinc ores but the third contains both sphalerite and galena together with their accompanying minerals.

Smith and Siebenthal[29] mention only two varieties, apparently classing the second and third together as one variety under the name jasperoid. Smith regards this jasperoid as being formed by the metasomatic replacement of limestone. A very complete description of the material and a discussion of its relations is given in the folio cited.

The discovery of gradations between limestone and jasperoid makes a strong case for the idea of the formation of jasperoid by replacement

28. Missouri Bureau of Geol. & Mines, vol. IV, 2nd. series, pp. 30, 37-40.

29. Joplin District folio (No. 148), Geol. Atlas U. S., U. S. Geol. Survey, 1907, pp. 13-14.

of limestone but in many cases the appearance of the breccia makes it hard to believe that all the jasperoid could have been produced in that way. The presence of the sharp angular fragments of primary flint would be practically impossible in primary limestone, and if the breccia were ever recemented by calcareous cement, it is very strange that so few traces of the calcereous portion remain since the recementation must have taken place after the fracturing of the chert. If the spaces between the angular pieces of primary flint represent the size and shape of limestone fragments which were present in the breccia when it was first formed. these fragments were extremely angular and different from anything

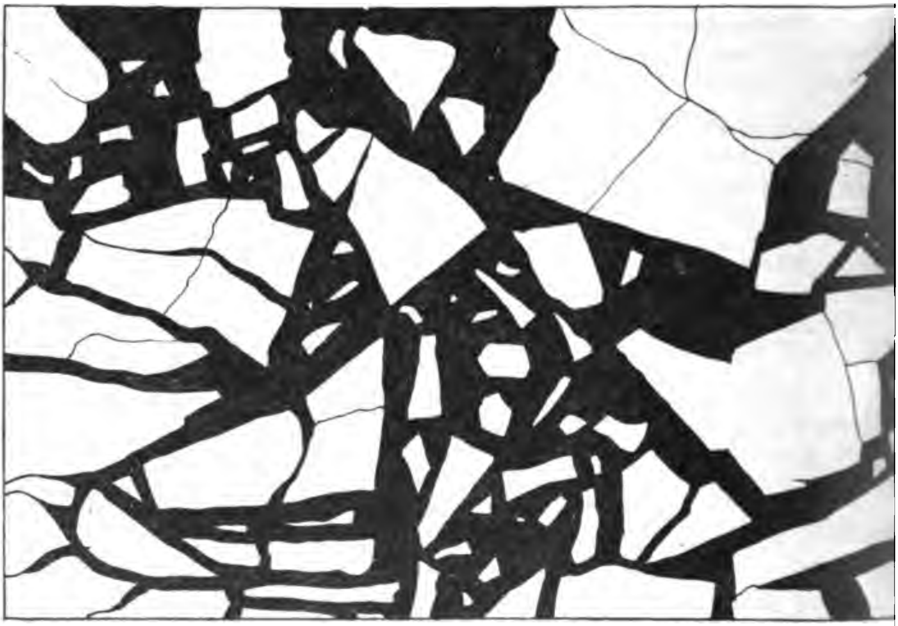


Fig. 8. Flint Breccia. Drawn from a specimen collected from one of the mine dumps (Mo. Bureau of Geology and Mines).

now known in Oklahoma. The absence of limestone from the breccia does not seem to require the replacement of the limestone for an explanation, for as has been pointed out by Buckley and Buehler in the report previously mentioned, the hill sides of the entire Boone area are covered with a mantle of loose angular chert fragments which show no limestone, although the formations from which this material is produced generally contain more limestone than flint. The writer therefore, believes that the "breccia" as it is shown in Oklahoma, is derived from a basal conglomerate of weathered chert fragments such as occur on the hill sides of the region at present, and that the black secondary flint or

jasperoid, at least in part, was deposited from solution in a colloidal condition. The white or gray secondary flint is probably a metasomatic replacement of limestone.

Limestone. The occurrence of limestone in the Boone formation has already been noticed. In relation to the mining industry it is important from the standpoint of its solubility, the solution of the limestone having produced the physical conditions favorable to ore deposition. The limestone occurring in the mines is always barren of ore. The ore bodies may pass around bodies of limestone, but never through them.

Sandstone. Sandstone is seldom important in relation to the lead and zinc mines of the Joplin district of Missouri, but in the Miami camp it forms the mineral bearing rock in most of the ore so far produced. The fine-grained sandstones have been broken and brecciated by settling into cavities formed by the solution of underlying limestones. The ore occurs in the brecciated sandstone in the same manner as it does in the brecciated chert in the other camps in the district.

Shale. The Cherokee shale forms the surface rocks at the Miami camp and occurs in small patches farther to the east. A black carbonaceous shale lies immediately above the ore bearing horizon at Miami and Quapaw mines. It is badly crumpled and slickensided by the movements of the rocks.

Clay. Clay occurs in the shallow diggings and in pockets and openings in workings of moderate depth. It is a very fine-grained plastic clay ordinarily of yellowish or a reddish color and is called "tallow" clay by the miners. Analyses of the clay usually show considerable percentages of zinc in the form of calamine. The calamine ore at Peoria occurs in a stiff, very plastic, red clay.

Calcite and dolomite. These minerals in crystalline form occur very abundantly in the Missouri mines where they are generally known as tiff and spar. The presence of dolomite was taken by Bain to indicate the origin of the ores in the Cambro-Ordovician limestones. In Oklahoma, however, both minerals are comparatively rare in connection with the ores. Calcite is found in a few cases in the Miami camp but no dolomite has been observed. Both occur in small quantities in some of the mines at the Quapaw camp.

Barite. Barite is very abundant in the lead mines of southeast Missouri and also locally in the Joplin district. It has not been reported from the Oklahoma camps.

Bitumen. A soft asphaltic bitumen is present in pockets and crevices in many of the mines of the Joplin district. In some cases it is in sufficient quantity to cause considerable trouble in concentrating the ores

as it causes the material to "ball up" in the jig cells. It also lowers the grade of the concentrates. This is especially true in the Miami camp where the bitumen is unusually abundant. As the water is permanently lowered by pumping or by the opening of mines with a lower water level. the bitumen seems to follow the water and practically disappears. The bitumen is probably derived from the Cherokee shales since it occurs most abundantly in the mines under or near the shale outcrops. Bitumen is very abundant in the shales. A body of almost pure asphalt in the Cherokee shales about two miles north of the Miami camp is two feet thick and covers several acres. On the other hand the Boone chert at a distance from the shale outcrops is never noticeably bituminous and the spring water from it shows no trace of oil.

Pyrite and marcasite. The iron sulphide, pyrite or marcasite according to crystallization, is called "mundic" by the miners. It is an almost constant accompaniment of the lead and zinc ores, usually occuring in crystals on the surfaces of the blende and galena. It also occurs in the Cherokee shales, some especially fine specimens of pyrite having been picked up along Tar Creek east of the Miami camp.

The great amount of pyrite in the concentrates from the Miami camp lowers the grade of the ore very markedly. The complete separation of the pyrite from the sphalerite by the concentrating methods in use is almost impossible owing to their having so nearly the same specific gravity. Pyrite and marcasite are very similar in appearance. In the remainder of this chapter the term pyrite is used to refer to iron sulphide although marcasite probably forms a portion of the material called pyrite.

Chalcopyrite. Chalcopyrite, copper-iron sulphide, occurs as small crystals in the dolomite of the Joplin region. In Oklahoma, no chalcopyrite has been observed but on some of the oxidized ores in the Quapaw camp there are green stains which are probably malachite produced by the oxidation of chalcopyrite.

Greenockite. Greenockite, cadmium sulphide, forms a yellow coating on the surface and in cracks of the sphalerite, in the Quapaw camp. No crystals have been observed.

SHAPE OF THE ORE BODIES.

The subject is discussed fully by Smith and Siebenthal in the Joplin District folio of the United States Geological Survey and extracts from that report are given below:

"The forms of the ore bodies, some simple, others complex, all fall into two general groups, the first including runs and their modifications;

the second consisting of blanket veins, or, as they are generally known in this district, sheet ground deposits.

Runs.

"Runs are irregular but usually elongated, in places tabular and inclined, bodies of ore, uniformly associated with disturbed strata which have been subjected to brecciation, slickensiding, and moderate displacement as the result of minor faulting or of dislocation due to underground solution. Simple runs are linear and continuous, straight or simply curved, ore bodies, usually at nearly the same level throughout their extent. On account of the complication of minor faulting, underground solution, and general deformation in the ore-bearing areas of the district, such runs are rare. Many runs which have a simple structure in cross section and which for short distances appear to be simple runs are found on further exploration to be compound. Even the few instances of simple runs which have been noted may present more complex features as the development of the ore body proceeds. It thus happens that there are all gradations from simple runs to complicated compound runs. Among the latter are those formed by the lateral connection of two nearly parallel simple runs so as to form a single ore body. Another class, comprising by far the larger number of runs in the district, consists of the irregular ore bodies formed in disturbed areas that are due to complicated underground drainage. Combinations of these give runs of great complexity, among them, here and there, circular or subcircular deposits. It will be seen, therefore ,that while theoretically the different types of ore deposits are distinct, practically they grade into one another, with no hard and fast lines between them.

"The greatest dimension of the runs is horizontal, although as compared with that of ore bodies in other regions this linear extent is generally short, as a rule not exceeding a few hundred feet. The Arkansas run at Belleville, with a length of over one-fourth of a mile, described by Bain, is exceptionally long. It does not, however, preserve a uniform direction, but varies from southeast to east, then to south, and finally to west. The runs have a maximum width of 300 feet, but as a rule are between 10 and 50 feet wide. The average vertical extent is about the same, but in some cases reaches 150 feet.........................

Circles.

"Circular, subcircular, and roughly elliptical closed runs, commonly known as "circles," constitute one of the most distinctive and constantly recurring types of ore bodies in the district.........................

"The common structural relations that have been described for the simple runs likewise prevail in the circle deposits, though, owing to

variation in texture and perhaps in initial structure of the rocks, the circles are not as a rule equally developed throughout, the width, vertical extent, and general character of the brecciated zone and the associated ore deposit varying more or less in different parts of the circle. The circular zone of ore-bearing chert breccia, grading into the country rock on the outside, is separated from the dolomite zone, which either forms a ring inside of this ore body or more or less completely fills the central mass or core of the circle, by a more or less sharp plane of demarcation which shades outward all around the circle. The larger slabs of chert in the breccias usually have an outward radial or quaquaversal dip, and in places the same is true of the limestones and dolomites making up the central barren core, which in such instances has a dome structure.

"Thus the ore body has generally the form of a cylinder, dome, or truncated cone, and a horizontal section except near the top of the dome has the shape of a circular or elliptical ring. In vertical extent, mode of occurrence, and character of their ore deposits circles do not in general differ essentially from the simplest runs, and like them are associated in many places with an irregular overlying area of shale. From the hooked and curved forms of runs all gradations to typical circles can be observed. and manifestly they should be ascribed to a common origin. As previously set forth, they are believed to be but special cases of the effects of underground solution.

Sheet Ground or Blanket Veins.

"Blanket veins, or, as they are more commonly known, "sheet ground" deposits, are nearly horizontal, tabular ore bodies, many of them of great lateral extent, developed parallel to the bedding planes of the rocks. They are to a certain degree limited, much as the runs are, to valleys and to areas of brecciation and solution.

"The ores of the sheet ground are both galena and sphalerite, occurring in part along the bedding planes of cherts and in part in breccias resulting from slight folding or faulting of the bedded rocks or from slight differential horizontal movements between the beds. In the breccias the ores occur either directly as cement or disseminated in jasperoid. As found along the bedding planes, the ores are either in cavities formed by solution, chiefly of thin intercalated beds or lenses of limestone, or else in jasperoid, which results from a metasomatic replacement of this limestone. The jasperoid thus occurs in sheets or lenses of variable thickness, from a fraction of an inch to 6 inches or more. Locally it completely fills the interval between the beds of chert; in many places, however, there are open spaces here and there between it and the chert above.

"In these cavities more or less ore has crystallized and either lines

or completely fills the cavity. Sphalerite usually forms on the bottom of the cavity, while galena, in places with marcasite on or about it, tends to form on the roof. Where the cavities have been completely filled the filling may consist wholly of sphalerite or galena, or of sphalerite in the lower part and galena, with or without marcasite, above. Locally a bed of limestone, especially where thin, may be completely removed without replacement by jasperoid, the filling of the cavity thus formed resulting in a sheet composed wholly of granular sphalerite or galena or of both.

"The ore of the cavities locally occurs in two or more generations. A first generation of sphalerite with galena may be coated with a later generation of sphalerite, both generations of this material consisting essentially of "rosin jack." A still later generation of both sphalerite and galena is often seen, the crystals usually small, or at least smaller than those of earlier growth, the galena in many cases of different habit, and the sphalerite largely of the variety known as "ruby jack."

"The horizons of the sheet ground, unlike those in which the runs occur, appear to be well defined. Small deposits of this character occur, in association with runs, at various horizons throughout the Boone formation, and in particular just above the Grand Falls chert, but the typical sheet ground seems to be developed invariably in the Grand Falls chert.

"The sheet ground, as a rule, is firm, requiring for the support of the roof only scattered pillars which are left at irregular intervals, usually in the leaner parts of the ore body..........................

"The sheet ground is fairly uniform in its ore percentages for considerable distances, such as might be included within the limits of a single mine, but it varies considerably at greater intervals. The percentage of ore is on the whole considerably lower than the average in the runs, but this is to a certain extent offset by the lateral extent of these deposits, by their occurrence at a single horizon, nearly level, and by the usual ready separation of the rocks along the bedding planes, all of which conduce to ease and rapidity of ore extraction. Another advantage is that the dead expense of prospecting in following the ore of runs is practically eliminated in sheet ground. The ground requires blasting, however, and on account of the predominance of siliceous material the drills are rapidly worn down and the rolls worn out in milling. With 2 or $2\frac{1}{2}$ per cent ore, the mines in sheet ground, as worked at present and at current ore values, scarcely more than make expenses. From this percentage the yield of the ground as worked ranges locally up to 25 per cent or more of ore."

All the forms mentioned as occurring in the Joplin district occur in Oklahoma. The ore body at the Miami camp is a run which probably

exceeds in length any of those mentioned as occurring in Kansas or Missouri. The apparent length of this run is over one-half mile although it is possible that the run nearest the surface at the south end of the camp plays out to the north and that the ore at the north end is from a deeper run. In any event the run is continuous for over one-fourth mile. Small runs and circles as well as sheet or blanket ground occur in the Quapaw camp.

THEORIES OF ORIGIN OF THE ORES.

The various theories of origin of the lead and zinc deposits of the Mississippi Valley and of the Ozark region have been discussed fully in several reports and papers, the principal ones of which are given herewith:

The Ore Deposits of Southwestern Wisconsin, by T. C. Chamberlin, Geological Survey of Wisconsin, volume IV (1873-1879), 1882.

Lead and Zinc, by Nrthur Winslow, Missouri Geological Survey, volume VII, 1892, pages 467-487.

Lead and Zinc Deposits of the Mississippi Valley, by W. P. Jenney, Transactions of the American Institute of Mining Engineers, volume XXXII, 1894.

Lead and Zinc Deposits of the Ozark Region, by C. R. Van Hise and H. Foster Bain, United States Geological Survey. Twenty-second Annual Report, Part II, 1901.

Special Report on Lead and Zinc, by Erasmus Haworth and others, University Geological Survey of Kansas, volume VII, 1904.

Geology of the Granby Area, by E. R. Buckley and H. A. Buehler, Missouri Bureau of Geology and Mines, volume IV, second series, 1905.

Geology of the Disseminated Lead Deposits of St. Francois and Washington counties, by E. R. Buckley, Missouri Bureau of Geology and Mines, volume IX, Part I, second series, 1908.

For the purpose of this report it is deemed advisable to give only a brief statement of the two leading theories as developed for the Ozark Region by Van Hise and Bain in Part II of the 22nd Annual Report of the United States Geological Survey, and by Buckley and Buehler in vol. IV, 2nd series of the Missouri Bureau of Geology and Mines.

All who have examined the deposits agree that the ores were deposited from solution in ground water. There is no evidence of igneous activity in the region although the miners have several terms such as "blow outs" indicating such an origin. The theory of igneous origin is entirely untenable in any portion of the Mississippi Valley and may be disregarded.

While there is no question as to the aqueous origin of the ores, there are two distinct theories as to the method of deposition. One school, the ascensionists, believe that the ores were first deposited by ascending currents of water and later concentrated by descending currents, while the other school, decensionists, believe that only descending currents have had any important part in ore deposition.

Jenney, Van Hise and Bain have been the principal adherents to the doctrine of deposition by ascending waters and concentration by descending waters. The source of the ores is believed to be the Cambro-Ordovician dolomites and limestones. Waters from these dolomites and limestones carrying the metals in the oxidized forms are thought to have passed upward through the Devonian shales and the Mississippian limestones. The oxidized compounds were reduced by the organic matter in the Devonian shales and also by the mixing of the artesian circulation with the circulation from the surface. The ores were deposited throughout the Mississippian limestones and cherts and on up into the Pennsylvanian rocks and were later concentrated at or near the surface by the erosion of the upper rocks and the solution of the ores contained in them by the descending waters. This ore was then deposited by coming into contact with reducing media. The principal deposition took place in the open chert "breccia" at the base of the Pennsylvanian rocks, which was taken by Bain to be a fault breccia.

This theory was founded on several conditions such as (1) the supposed presence of deep faults which would pass downward through the Devonian shales and into the Cambro-Ordovician limestones and dolomites; (2) the artesian character of the mine water, Bain making the statement that the amount of water pumped from the mines did not vary with the season; (3) the association of dolomite with the ores, which was regarded as being practically universal and which was supposed to indicate the origin from the Cambro-Ordovician dolomites.

Buckley and Buehler in the report on the Granby area have shown that Bain was mistaken in his interpretation of the conditions in the district, and (1) that what he supposed to be faulting was due to an unconformity at the base of the Pennsylvanian, and to minor readjustments of the Pennsylvanian rocks to an unevenly eroded surface, and to a sink hole topography, (2) that the breccia was not due to faulting but to the cementation of the surface chert fragments such as now cover the surface in the region, (3) that the mine water varied greatly in wet and dry seasons, (4) that the dolomite was by no means a constant accompaniment of the ores and was no greater in amount than can be accounted for by solution from the shales and limestones of the Pennsylvanian and Mississippian, (5) that the organic matter which was probably the precipitating agent was almost certainly derived from the overlying Pènnsylvanian shales, (6) that from an upward circulation the lead

sulphide would have been deposited in the lowest levels of deposition, reversing the conditions as found in the district, (7) that the Pennsylvanian shales contain sufficient lead and zinc to account for the ore bodies, while the waters from the Cambro-Ordovician rocks contain mere traces of the metals.

Haworth, in the Kansas report referred to above, as a result of careful investigations estimates that more than 90 per cent. of the mine waters in the Galena district can be accounted for by the rainfall in the district and the territory immediately to the east. He states that it would be impossible for the rainfall on the outcrop of the Cambro-Ordovician rocks in southeast Missouri to supply more than a tithe of the water pumped from the mines at Galena.

Smith and Siebenthal in their folio on the Joplin District accept (with some modifications) the Van Hise-Bain theory of deposition by ascending waters and apparently regard the association of ore bodies with the outcrop of the Pennsylvanian rocks as largely accidental. They do not, however, find any great faults or attempt to account for the upward circulation of the ground water.

In this connection it is interesting to note that the most recent work in the northern Illinois-southwestern Wisconsin district, the region to which Bain first applied the theory of deposition by ascending water, tends to show that the ores are derived from the Maquoketa shales which overrlie the ore bearing rock instead of from the limestones which underlie it, in other words that the ore has been deposited from descending waters[30].

The bearing of observed facts in the Oklahoma field is in the same diection. No deep seated faults are observed in the productive areas, and on the other hand ore is not known to occur in the deeply faulted area to the south of the producing field. The large faults do not produce a fault breccia of such extent as the "breccia" in the producing areas. There is very little calcite and practically no dolomite in connection with the ores. The water in the Peoria and Lincolnville camps is not artesian and that in the Miami camp can probably be accounted for by the rainfall on the territory immediately to the east. The ores are intimately associated with outcrops of the Pennsylvanian shales which contain small quantities of galena, of sphalerite and considerable pyrite and bitumen.

DESCRIPTION OF THE MINING CAMPS.

Up to the present time three mining camps have been developed in the portion of the Joplin district lying in Oklahoma. These are in

30. Cox, G. H., Elizabeth sheet of the lead and zinc district of northern Illinois, Bull. Ill. Geol. Survey, No. 16, 1910 .

order of age, the Peoria, Quapaw or Lincolnville, and Miami. Their location is shown on the accompanying map (fig. 8.)

The Peoria Camp.[31]

Location. The Peoria camp is located at the village of Peoria, six miles south of the Kansas-Oklahoma and three miles west of the Missouri-Oklahoma line in sec. 12, T. 28 N., R. 24 E. of the Indian Meridian. Some digging has been done in sections 13, 14 and 15.

History of development. The first work was done in this camp by the Peoria Mining Company in May, 1891. The town of Peoria, the first town incorporated in Indian Territory, was laid out and incorporated in 1892. The Peoria Mining Company sold about $1,000 worth of ore during 1891 and 1892. In 1893 the company was reorganized as the Peoria Mining, Construction and Land Company. From May 1, 1893 to September 16, 1894, 2,726,418 pounds of galena were produced and hauled by wagon to the Joplin White Lead works where it was sold at $44 per ton. During the same time 56 tons of sphalerite (jack) and 332 tons of silicate were hauled to Baxter Springs, Kansas, where the sphalerite was sold for $11 per ton and the silicate for $8 per ton. The value of the production of the camp during this period was about $63,250.

The absence of transportation facilities worked a hardship on the camp in rendering the marketing of the ore very expensive and by making it difficult to secure and hold suitable labor. As a result development since 1894 has been on a small scale and of an intermittent nature. The following quotation[32] gives the conditions of the camp in 1907.

"The mines at Peoria were opened in 1891 on land the first lease of which is held by the Peoria Mining, Construction and Land Company, a New Jersey corporation. The most productive area adjoins the village on the northwest, and underlies the bottom and north bluff of Warren Branch. In the creek bottom, over an area 300 feet long east and west by 100 feet wide, known as the Playhouse diggings, a solid sheet of galena was found in chert at a depth of 7 to 10 feet. This sheet, narrowing to 60 feet, extended northward for 600 feet under Monkey Hill and is reported to have been from 6 to 22 inches thick. Other shallow deposits of lead have been worked on the first and second hills west of Monkey Hill. Not much sphalerite has been mined at these places. A sheet of sphalerite from 4 to 18 inches in thickness, with a thin sheet of galena just above it, which yielded two carloads of ore, was struck about 12 feet above the level now worked for silicate.

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31. For the information regarding the early days of the Peoria camp and the presence of the deeper ores I am indebted to Mr. J. P. McNaughton of Miami, Oklahoma.

32. Siebenthal, C. E., Bull. U. S. Geol. Survey No. 340, 1907, pp. 201-202.

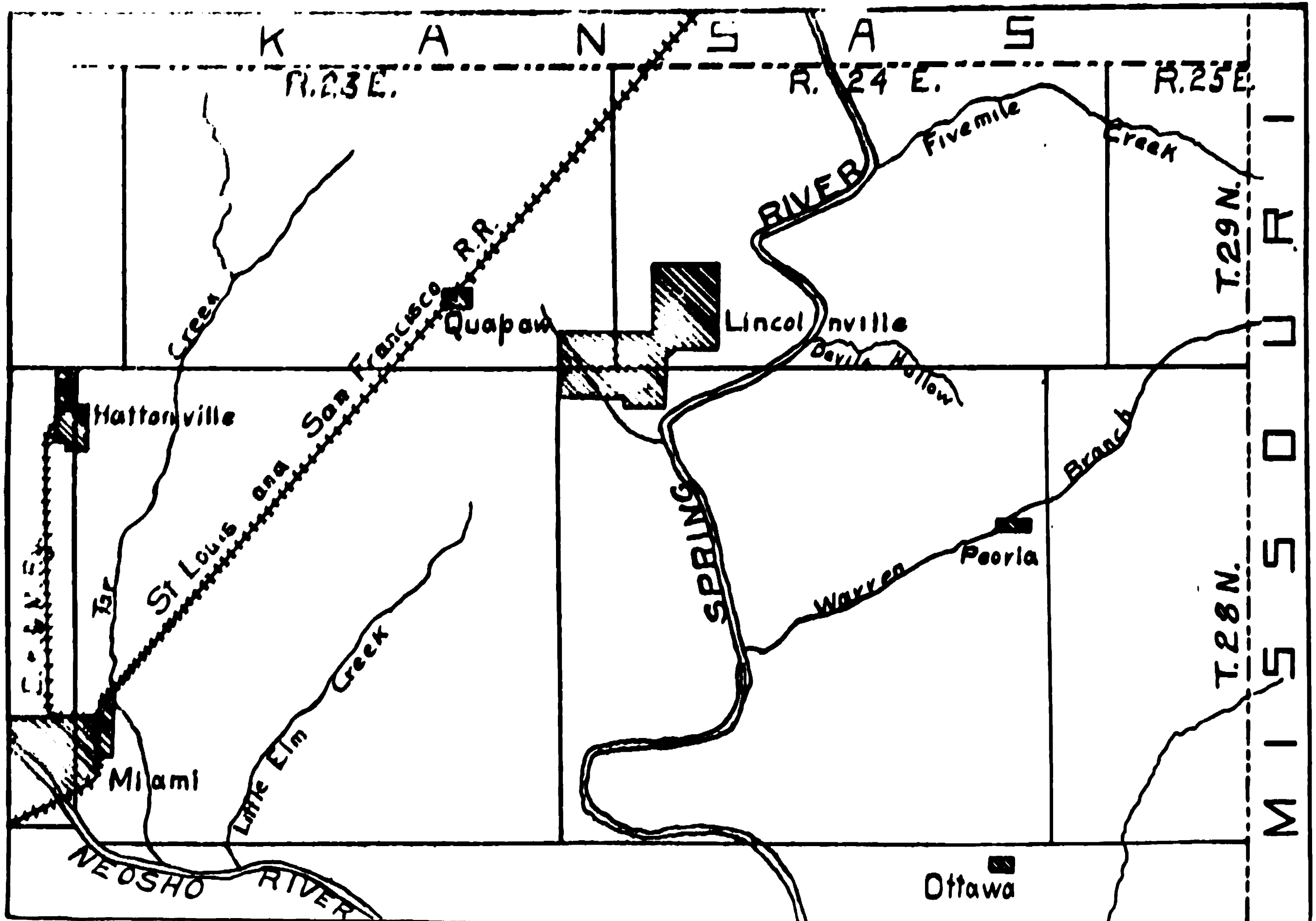

K A N S A S
M I S S O U R I
R.23E.
R.24 E.
R.25E.
T.29N.
T.28N.
St Louis and San Francisco R.R.
Quapaw
Lincolnville
Devils Hollow
Hattonville
Miami
Peoria
Ottawa
SPRING RIVER
NEOSHO RIVER
Fivemile Creek
Warren Branch
Little Elm Creek
Creek

Fig. 8. Map of

"*Silicate mine.* The Silicate mine is operated by Gordon & Wilkins. The shaft is in the face of the hill just north of the creek, about 50 feet west of the edge of the Playhouse diggings, and some of the drifts extend under those old workings. The face of ore ranges from 1 to 7 feet in height, averaging 2½ feet. The drifts are carried 6 to 8 feet in height and from 10 to 12 feet in width, and have a total length of approximately 1,000 feet, covering an area less than 200 feet square. The ore occurs either in slabs or as "fish-egg silicate," in clay interbedded with red tallow clay and layers of soft, rotten chert, the whole conforming to the limestone horses and bowlders which are present here and there. In one place the walls of the run closed in, nearly pinching out the ore, which continued on through the opening in the solid limestone. The ore in the main is plainly the result of a carbonate replacement of the limestone country rock, associated with more or less underground solution, the latter in part antedating the ore deposition, giving rise to the openings through which the ore-bearing solutions passed, and in part contemporaneous with the ore deposition. The ore is concentrated on hand jigs, the quantity of fine fish-egg silicate associated with flat shapes requiring an elaborate scheme of concentration. Women and girls are employed to hand pick the screenings—probably the only instance of such employment in the Joplin region.

"*Chicago Syndicate Mining Company.*—In 1907 the Chicago Syndicate Mining Company erected a mill over some old workings half a mile northwest of Peoria. The level worked at the mill shaft is 120 feet deep, but at another shaft on the edge of a small, oblong solution patch of shale and sandstone of Chester age, the mining was done at the 160-foot level. A considerable amount of lead was taken from this shale patch at a depth of 12 to 22 feet, the ore occurring near the base of the sandstone and shale. In the drifts now being worked the ore is sphalerite disseminated in rather coarse crystals through the bluish-gray jasperoid cement of chert breccia. In places this cement makes up one-third to one-half of the mass of the breccia, the chert bowlders and slabs being suspended in it. Considerable spar is present here and there, and where decomposition has progressed far there is much tallow clay.

"*Other mines.*—The Poor Boys Mining Company is operating a silicate mine, and several other companies are prospecting in the immediate vicinity of Peoria.

"Three miles due east of Peoria, on a tract of land belonging to S. L. Davis and adjoining the State line, in the vicinity of the Pinnick mines, there have been some recent strikes of ore. The Grimes & Williams shaft is sunk near the border of a circular solution patch, bordered by an outcrop of brecciated chert with a jasperoid matrix showing impressions of sphalerite crystals which have been leached out. Within the circle there are scattered sandstone bowlders of Chester age. The ore is

sphalerite and occurs at the 90-foot level in the matrix of the chert breccia. This matrix consists of jasperoid in some places and of dolomite in others; in still others the ore itself acts as the cement. In the McKisson shaft, on the same tract, a 3-foot run of lead was struck at the 60-foot level in yellow flint ground."

Since 1907 there has been very little new development and only a few new prospects have been made. The mill of the Chicago Syndicate Mining Company has run very little. The Silicate Mine has been worked on a small scale most of the time. At present the silicate is separated from the stiff red clay in which it occurs, by sluicing with water pumped from the shaft by means of a gasoline engine. In dry seasons the water from the sluice box is run back into a sump at the bottom of the shaft, and is used over and over. A small production of silicate is made from several other shafts in the neighborhood.

Very little prospecting for deeper seated ore has been done. A few holes are reported to have shown considerable bodies of low grade sulphide ores in sections 12 and 13 but the head of water is so strong that concerted action would be necessary to lower it.

With the present conditions of transportation there does not seem to be any immediate prospect of great development in this camp, but if a railroad should be built through the camp and if further prospecting should show that the sulphide ores of the deeper levels are present in quantity, the Peoria camp has a good prospect of becoming an important producer.

The Quapaw or Lincolnville Camp.

As is the case for the Peoria camp, the Quapaw camp has shown little development since 1907 when the article by Siebenthal, which has been used extensively in this report, was written. His remarks on this camp are therefore given in full and afterward a few notes showing the present condition of the camp. The state of development of the camp in 1908 is shown in figure 9.

Introduction. "The Quapaw mines extend from 1 to 4 miles east of Quapaw station, and from 5 to 7 miles south of Baxter Springs. The ore-bearing ground has been proved by drilling to extend for some distance beyond these limits on all sides, notably to the west, in the vicinity of Quapaw station, where a good strike was made in drilling the town well. The main ore deposits occur at a depth of 80 to 150 feet in blanket-ground formation, rarely in confused broken ground. Ore at shallower depths is limited chiefly to the region lying immediately south of Lincolnville, the village at the Quapaw mines. On the eastern edge of the Quapaw district the blanket ground rests upon the Short Creek oolite member of the Boone formation, which is usually penetrated by the

mine sump. Though doubtless the blanket breccia forms an uninterrupted sheet throughout the area of the Quapaw mines, the oolite is not found in the western mines. This is because the bed, as noted in its description, thins out or loses its oolitic character along a north-south line which bisects the district. The ores found in the blanket ground are sphalerite and lead in about the proportion of 5 to 1. In a part of the blanket ground there has been some oxidization in the upper part and a little calamine is present. No ore is mined below the Quapaw blanket ground, although the drill has shown ore at deeper levels. In the shallow ground, the ore, which is principally silicate and galena, occurs in runs and circles. In addition to the circular solution patch (with a probable circular ore deposit) on the Cherokee Lead and Zinc Mining Company's land, described below, there are several other shale and sandstone patches of the same shape. A circular shale patch at the FFF mine had much sphalerite and pyrite in the lower part of the shale, and ore continued in broken ground down to the main blanket ground at 90 feet. There is a large circular solution patch on the Red Eagle tract, in the NE. ¼SE. ¼ sec. 31 T. 29 N., R. 24 E. The shale area is 350 feet in length north and south by 300 feet in width. A shaft near its southeastern margin shows a thickness of 70 feet of shale. The shale area is surrounded by a low rim of chert which dips away from the center on all sides. Near its contact with the shale the chert is brecciated and recemented with jasperoid from which considerable sphalerite has been leached. It seems reasonably certain that the ore here, should it occur in workable quantity, will be found in circular shape.

"There are in the Quapaw district 25 steam concentrating plants, with a daily capacity of 3,300 tons, besides 7 mines operating hand-jig plants. In the typical blanket ground hand jigs can not be operated to much advantage, as the ore must be crushed very fine to free it from the rock. Those in operation are working with dirt from the shallow ground or the more oxidized portions of the blanket ground. In addition to the mines with concentrating outfits there are about 30 prospects which have shafts down to the ore. The owners of some of these prospects have planned to build mills; others are waiting for ore prices to become better.

"*Cherokee Lead and Zinc Mining Company.*—In a field on the Cherokee Lead and Zinc Mining Company's lease just southwest of Lincolnville several wagon loads of calamine were picked up, having been plowed up and cast aside in ignorance of its value. Approximately 50 tons of silicate with a little lead were taken from shallow open cuts less than 15 feet in depth, along the southwest margin of a circular solution patch at this place. Limestone and sandstone of Chester age cover the surface except for the circle 125 to 150 feet in diameter. The border of the circle is marked by a ring of sandstone bowlders. Inside this ring shafts and borings strike Cherokee shale with a little coal. Between

the sandstone ring and the adjacent limestone there is, along the sout west margin, a strip of chert breccia with a matrix of jasperoid. Th matrix has been ore bearing, as shown by the cavities from which spha erite has been leached. The ore found in the shallow diggings lay mainl between the breccia and the limestone, but also extended in clay seam into both the limestone and the jasperoid. In the shaft just west o the circle ore was found at a depth of 35 feet in the clay and lime stone bowlder filling of a solution chamber at the base of the limestone of Chester age.

"A sheet of lead ranging up to 6 inches in thickness was struck at a depth of 40 feet in the shaft of the Alabama Mining Company, a hundred yards south of the locality just mentioned.

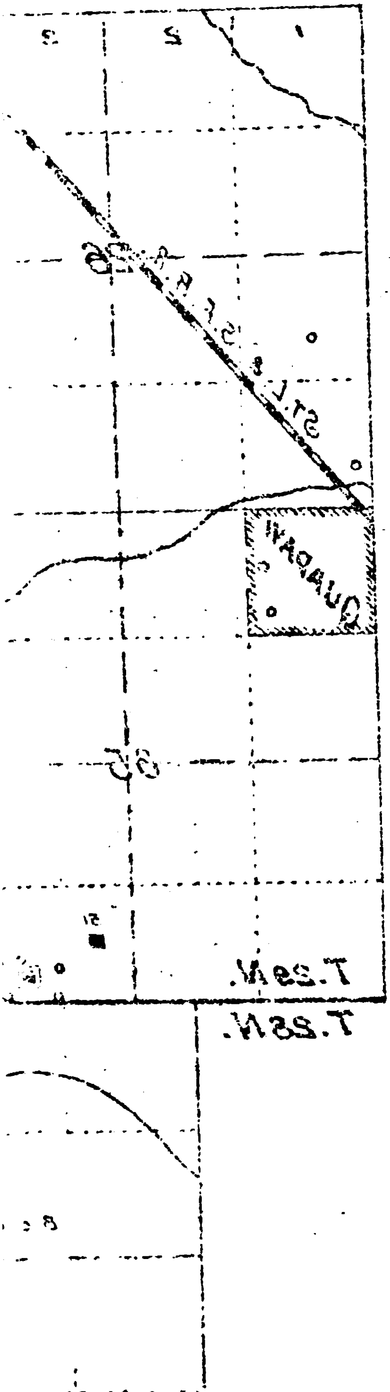
"*Good Luck mine.*—Soft "confused ground" occurs at the Good Luck mine, as well as in some other mines in the northeastern portion of the Quapaw district. In the No. 1 shaft of the Good Luck mine the soft ground joins the blanket ground along a north-south line and the east-west drift is partly in each kind of ground. The blanket ground exposed by the drift is fractured and broken, but not recemented, and in places the bedding is entirely obscured. Clay and shale occur in the fractures and joints and between the chert beds. The blanket ground was evidently much softened by the solution which is responsible for the confused ground adjoining. The latter is the typical soft ground of chert and limestone bowlders in soapstone and yellow clay. Tiff and pink spar are present in veins and pockets in the unoxidized ground and impressions of spar and sphalerite occur in the jasperoid cement of the oxidized ground. Weathered lead occupies seams and fractures in the jasperoid. The No. 2 shaft was sunk on a drill hole showing rich lead cuttings that were found to have come from a solid chunk of galena a foot or two in thickness, which did not reach completely across the shaft. When followed to the south the lead gave out within 2½ feet of the shaft, but the drift soon ran into good zinc ore. The ground here consists of dull chert and rotten limestone bowlders in a matrix of shale, clay, and tallow clay. Some of the bowlders are of secondary limestone, highly crystalline and very rich in ruby sphalerite in grains of the same size as those of the limestone. In some of these limestone bowlders the sphalerite constitutes from 15 to 25 per cent of the mass.

"*Mission mine.*—The Mission mine may be chosen to exemplify the blanket-ground mines because it is typical, because its underground workings are the most extensive, and because it is the best-known mine in the district, having been the "show" mine from the beginning of the camp. The mined area extends over approximately 5 acres in the NE. ¼ sec. 1, T. 28 N., R. 23 E. The blanket ground is about 30 feet in thickness, the top of the ore being reached at about 50 feet from the surface and the limestone upon which it rests at about 80 feet. Only the


MAP SHOWING LOCATION
of
Mills, Shafts & Drills
LINCOLNVILLE DIST.
R. 24 E.
R. 25 E.
25
26
ROCK
CR.

Shafts.

No	Name
1	Virginia.
2	Quapaw Lead & Zinc Co.
3	Hannibal & St. Joe.
4	Pasture.
5	Common Law.
6	Nash, Kenedy & Nash
7	Cherokee
8	Diamond C
9	Hall
10	McAlister
11	Little Four.
12	E. L. Wright.
13	Canterbury.
14	Rock Creek.
15	McKinley.
16	Baldwin Martin.
17	Syndicate.
18	Chicago Quapaw
19	Big Squaw
20	Farmer Boy
21	Lone Elm.
22	Bliss.
23	Craney Bros.
24	Irish Maid.
25	Independence.
26	Cramer & Parker.
27	Murrito & Newland
28	Red Eagle.
29	Eleventh Hour.
30	Three Queens
31	First Chance
32	Good Luck
33	Sun Burst
34	Hobo
35	Triton.
36	Majestic
37	Dark Horse
38	Isley.
39	Gallin
40	Indiana
41	Eastman.
42	Gray Eagle.
43	Quapaw.
44	Lost Chance
45	Amos Kenedy.
46	Luther
47	Three Queens.
48	Mission.
49	Gaines
50	Virginia
51	Virginia



ıpper 18 to 20 feet of this ground has been worked, though at the time :he mine was visited a lower stope 10 or 12 feet in height was being taken ıp from the pump shaft.

"In this mine, as generally in the district, there is at the top of the ›lanket ground 2 or 3 feet of soft ground, containing more or less black shale and yellow clay. Locally solution has progressed so far that slabs only of limestone and chert occur in the shale and clay. There is as a rule more or less spar and tiff in veins and pockets, and here and there a little bitumen. Much of the shale is slickensided. This zone is apparently not one of general movement, but one of accommodation to the slight stresses resulting from underground solution and the weight of the superincumbent strata. It seems likely that the opening at the top of the blanket breccia, into which the clay and shale have been drawn, was largely a result of the settling of the chert beds when the interbedded limestone was dissolved. The fact that the roof did not settle into this space would be explained if the solution in the blanket cherts went on by areas, portions remaining to support the roof until after the portions first dissolved and fractured had been recemented by jasperoid and rendered capable of sustaining the roof. This upper, softer sheet is in many places richer in ore than the harder ground below, but on the other hand it is here and there entirely barren.

"Below the soft ground the blanket breccia consists of greatly fractured "live" blue flint, which in the more unbroken portions shows small dark spots one-eighth to one-fourth of an inch in diameter, surrounded by a lighter border. At many points the stratification of the chert is completely obscured by the brecciation, but in general it can be made out either from the chert or from the jasperoid sheets between the broken chert beds.

"The brecciation of the chert ledges is uneven. In places the whole ledge is broken up; elsewhere it is broken into large bowlders with finer brecciation between them; elsewhere still the sheets are comparatively unbroken, with chert fragments suspended in the jasperoid interstrata. In many of the more unbroken portions of the chert strata traces of a former fine brecciation may be distinguished. The outlines of the fragments are faint, and the cementing material resembles a network of thin dark veins. These are not ore bearing and possibly correspond to the older sheet brecciation in the sheetground deposits of the Joplin district. At numerous places in the mine the chert is fractured vertically or nearly so. Some of these fractures come so close together as to constitute "sheeting" and to conceal the bedding of the chert completely. They are ordinarily not slickensided, but are usually stained dark by the circulating waters. In general they are open, containing neither ore nor jasperoid. They are probably equivalent to the sheeting in the mines

of the sheet ground in the Joplin district, where also the sheeting is later than the ore deposition.

"The ore in the Mission mine consists of sphalerite and lead in the proportion of 2 or 3 to 1. The latter is found in fissures and crevices in the chert, and the former is disseminated in the jasperoid as well as in the crevices and fissures. Where both the ores occur in a pocket, the galena shows a tendency to be crystallized in the upper parts and the sphalerite in the lower parts. In the mine as a whole not much differentiation can be seen, more lead occurring in the upper portion in some places and near the bottom in others."

Condition of camp in 1911. Conditions since 1907 have not been such as to permit the low grade blanket ground ores to be worked on a small scale with profit. Besides many of the mills were built before sufficient prospecting had been done to insure a sufficiently large ore body to render operation profitable under any circumstances. Many of the mills have been removed and others have stood idle practically all the time since they were erected. From the appearance of the camp few of the mills have run sufficiently to pay for the cost of machinery and installations. Among the mills that have been removed are the Joanna, Big Squaw, J. C. L., Spring River, Lincolnville, Omaha, Hobo, Heap-O-Brien, Querera, Sunnyside, Dark Horse, Ayers-Sloan, Indiana, Mason, Ward, Lennox, and others.

In the autumn of 1911 only four mills were running. Two more were closed down temporarily and one hand jig and a few "gouging" propositions were being worked. The four mills being operated were the old Mission Mine, old M. K. & T., Big Jack, and Good Luck.

The Mission mine is operated by the Kansas City-Quapaw Company. The workings have been extended to the south and west and the new workings are at a level 8 feet lower than the old workings, and a face of 20 feet is worked. The old mill has been recently abandoned and a new 100 ton mill erected about 100 yards southwest of the old site. The ore is elevated through a new shaft at the mill. The longest drifts in the newer workings extend about 300 feet from the bottom of the shaft and there are several lateral drifts 100 to 200 feet long. The total number of headings or faces is above 60.

None of the drifts have reached the limits of the ore body and drill holes show it to continue to the south and west to the limits of the lease. No borings have been made for deeper ore but it is scarcely probable that large ore bodies are present below the blanket ground.

The "dirt" runs 30 per cent concentrates when properly culled. The concentrates average one-third galena and two-thirds sphalerite. The sphalerite concentrates are rather high grade, containing 56 to 60

per cent of zinc, and 2 to 3 per cent of iron. The galena is higher in the southern part of the workings and decreases rapidly to the north.

The mine water all seems to come from the surface and is easily handled. The mine, filled to the roof, is reported to have been emptied in four days of continuous pumping.

The old M. K. & T. (Katy) mine is owned and operated by the Petersburg Land and Mining Company, a Missouri corporation, which owns all of the SW. ¼ sec. 36, T. 29 N., R. 23 E. Borings show the blanket ground to be present under the whole 160 acres. A new 400 ton mill was erected in 1911 west of the site of the old Katy mill. The equipment consists of 2 crushers, 9 sets of rolls, 8 jigs and 6 Wilfley tables. Power is furnished by a 250 Horse Power Bessemer Gas engine.

The conditions in general are the same as those in the Mission mine to the south. The workings are on the 70-foot level and a 20-foot face is worked. About two and one-half acres have been worked out. Dirt is obtained from three shafts, 2 at a time. The ore from the shafts away from the mill is hauled in automatic end-dump cars on inclined tracks. The dirt produces about 3 per cent of concentrates which, however, are all sphalerite which assays 60 per cent zinc and between 1 and 2 per cent iron. Ordinarily 8 carloads of 30 tons each are produced each month.

The Big Jack Mining Company controls 11 acres in NE. ¼ sec. 6, T. 28 N., R. 24 E. Less than two acres have been cut out. The workings are in a soft ground containing considerable clay, on the 107-foot level. A face 14 feet high and 24 feet wide is worked. The run dips slightly to the west and becomes thicker but does not widen out. Timbering is necessary in the soft ground, and there is considerable water. The dirt runs about 6 per cent concentrates, sphalerite and galena in the proportion of 8 to 1. The sphalerite runs from 59 per cent to above 60 per cent of zinc and from 1 to 2 per cent of iron. Tiff and spar are associated with the ore. About 175 cars of dirt are handled per 10 hour shift. An upper run of 4 per cent ore 40 to 50 feet wide and 25 to 30 feet thick is not being worked at present.

The Good Luck Mine at the northeastern corner of the camp has been described in the quotation from Siebenthal. Work has continued at this mine and a large production has been made. In the fall of 1911 the mill was working ore from which 10 per cent of concentrates, all sphalerite, were recovered. The mill has a capacity of 100 tons per day.

The mill at the Lancaster mine to the south of the Good Luck burned in 1910. The Ethel Miller Mining Company is working a hand jig on the site of the old mill and has shipped several carloads of sphalerite. There is little galena in the ore, which is found in a hard ground.

develops the land if ore is found, to 50 per cent for proven mines equipped with mills.

Mining development. Under this heading a brief description of each of the mines is given with general data as to their workings, mill-

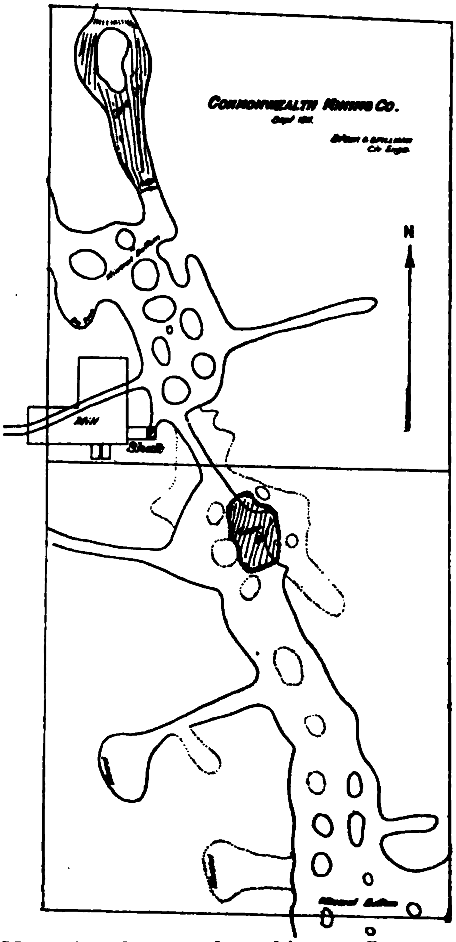


Fig. 11. Map of underground working of Commonwealth Mine.

ing equipment, output and ores. The properties on the main run are taken up in order south to north and then those on the minor runs in the same order. Finally a discussion of the prospecting outside of the developed portion of the camp is given. The arrangement of the properties is shown on fig. 10.

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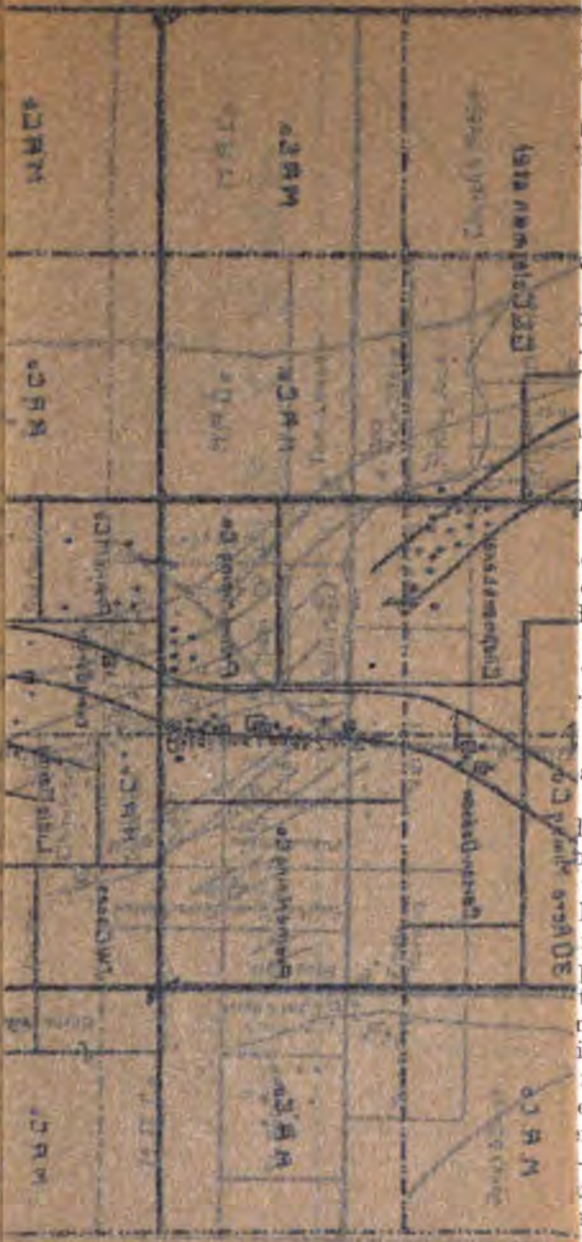

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The *Swastika* is the lease farthest to the south that has been worked o any extent. The ore was found at a shallow depth and was worked ut in a rather short time. A mill was erected but was later moved to he Sullivan lease operated by the Miami Amalgamated Company. The eeper run was found in a drill hole north of the mill site at a depth of 35 feet. If ore should prove to be present in quantity the lease will be evived.

The *Morning Star* (Commonwealth) lease has been mined out and he mill removed. The *Index* mine and mill was operated by the Kenwood Mining Company. Considerable production was made in 1908 and 1909. Operations were discontinued and the mill moved away. Both of hese leases will be prospected for the deeper ore and may be revived. A haft was sunk on the *Ben Hur* lease but apparently failed to show ore n paying quantities since there has been no further development. The nature of the underground workings in this portion of the camp is shown n fig. 11.

The *King Jack* mine was operated by the Temple and Chapman Lead and Zinc Company during 1908-09. A considerable production was made but the vein was worked out and operations discontinued for some ime. The Miami Amalgamated Company now has charge of the lease nd in the fall of 1911 was remodeling the mill and installing a modern gas engine. The shafts were being sunk to the lower run which was ncountered in drill holes at a depth of 165 feet. The holes showed over 30 feet of good ore, both lead and zinc. The upper run was worked t 90 feet and the ore was rich and the concentrates of high grade.

The *New State* mine now operated by the Kansas Mining Company has been one of the most consistent producers of the camp. A 100 ton mill was erected in 1907 but was not in steady operation until the middle of 1908, since which time the mine has been almost a constant producer. The ore is worked from two shafts one 112 feet deep and the other 100 feet deep. The run averages about 100 feet wide and has a face of 12-14 feet. In this mine the ore is rich, the complete returns m can runs for three months showing a recovery of 10½ per ent of consentrates, of which about one-fouth was lead. About 6 per cent of blende and galena are found in the tailings from the mill nd these are treated in a tailing mill equipped with six reciprocating ables. The zinc concentrates contain from 47 to 55 per cent of zinc, averaging 50-51 per cent, and 2 to 4 per cent of iron. Zinc concentrates from the tailing mill contain an average of about 45 per cent f zinc and 3 to 6 per cent of iron. The lead concentrates assay 80-81 er cent of metallic lead. Considerable ore is still in sight on the uper run and more can be obtained by removing the pillars which have een left to support the roof. Although the lower ore is also known to e present on the lease its exact extent has not been shown.

Merely the corners of the *Edna Ray* and *Tom Lawson* leases were crossed by the ore run and this was soon mined out. The mills which

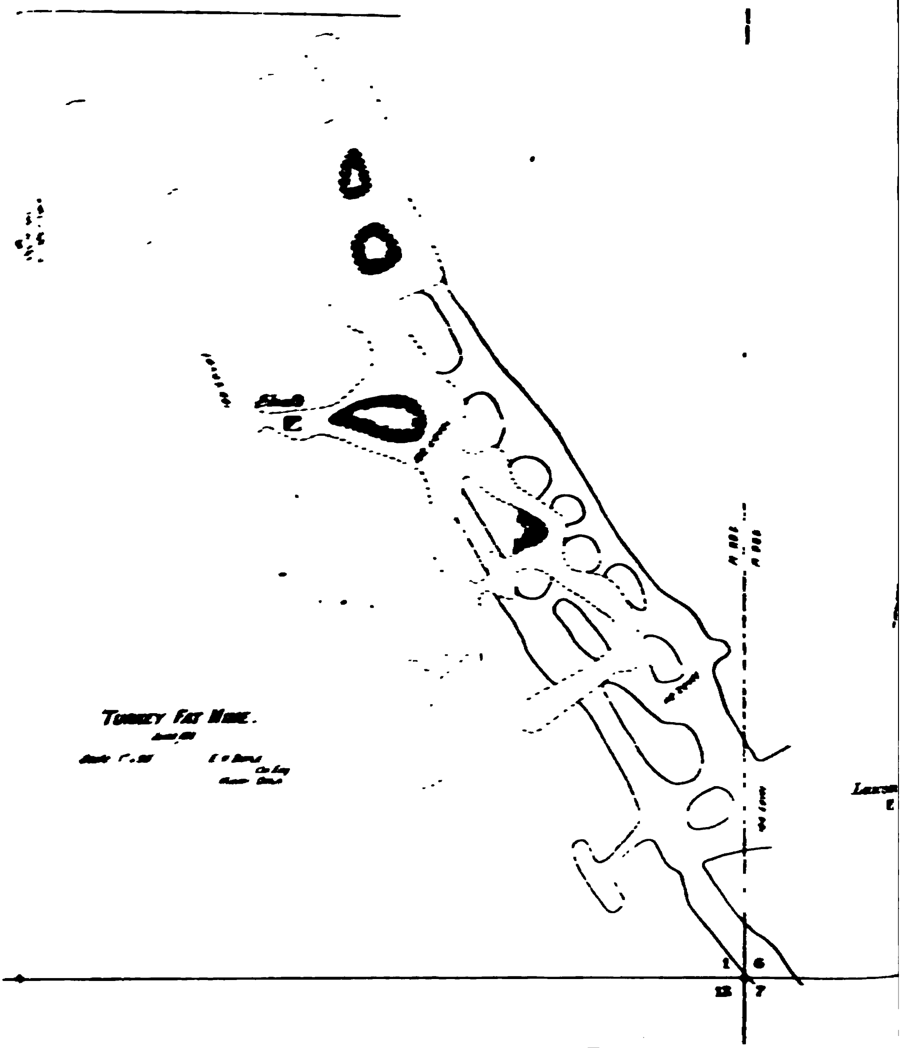


Fig. 12. Underground workings of Turkey Fat Mine.

were erected were soon removed, the Tom Lawson mill to Lincolnville and the Edna Ray mill to the Oklahoma lease.

The *Turkey Fat* lease consists of 10 acres of land with the main run crossing the southern end diagonally. This lease is the only one

which is operated directly by the Miami Royalty Company. The upper run of ore is found at 120 feet and averages about 16 feet thick and 20 to 50 feet wide. The one deep hole which has been put down (Nov. 1911) shows good ore from 202 to 225 feet. There is probably ore sufficient for a year's run in the upper ore body. The mill has a capacity of 100 tons of ore. In character the ore does not differ materially from that of the New State which has been described. The Turkey Fat has been second largest producer in the camp. The underground workings are shown in fig. 12.

The Miami Amalgamated Company operates the *Sullivan lease*, a square of 10 acres immediately west of the south half of the Turkey Fat lease. The upper ore run crosses the lease diagonally and is encountered at a depth of 110 to 125 feet. The ore carries about two and one-third times as much blende as galena. The blende concentrates usually carry 2½ per cent of iron. Deep holes have shown the lower run under the east side of this lease, and a good body of ore was shown from 200 to 250 feet. The cuttings assayed 30.69 per cent blende with very little galena. A shaft was being sunk to this deeper ore in the fall of 1911 when the writer visited this district.

One of the first mines opened in the camp was the *Old Chief* and this mine made considerable production in 1908, 1909, and 1910. The upper run was then exhausted and operations ceased. During 1911 the ground was prospected by the Standifer Mining Company and sufficient ore was found at a slightly lower level than the one which had been worked, to justify a resumption of mining.

The *Emma Gordon* lease, operated by the Standifer Mining Company, comprises 20 acres in a rectangle of two 10-acre squares, with the long dimension north and south. The ore run extends the full length of the lease. The ore has a face of 20 to 25 feet. Here the ore is very rich but contains much pyrite which materially lowers the grade of the zinc concentrates. The ores are treated in a 400-ton mill of the sheet ground type and the tailings from this mill in a tailing mill, equipped with 8 tables and operated by the High Five Mining Company. From February 5, 1910 to January 1, 1911 the average of the assays on the zinc concentrates from the big mill was, zinc, 45.56 per cent.; iron, 8.62 per cent. The average price received for the zinc ore was $23.34 per ton. Probably not over one-half of the upper run on this lease is worked out and the lower run is also known to be present but its exact limits have not been defined. The proportion of galena in the upper run is high but the lower run is practically all sphalerite.

The Oklahoma Lead and Zinc Company and the Carson-Dodson Company sublease from the Emma Gordon Company. A 200-ton mill has been erected on the former lease and ore is hauled by tram to this

mill from the Carson-Dodson shaft. The depth to ore on the Oklahoma lease is about 180 feet and on the Carson-Dodson about 215 feet. Development of these leases has been greatly retarded by the strong head of water. Two 6-inch centrifugal pumps were kept in almost constant operation for 7 months before the water was lowered sufficiently to permit the hoisting of ore from the Carson-Dodson shaft. The first ore was hoisted in the fall of 1911 and proved to be very rich, one days run producing over 50 per cent. of concentrates, a large proportion of which was galena. The Chapman-Lennon leases are also sublet by the Emma Gordon Company. A shaft has been sunk to ore and a mill erected but as in the other leases at the north end of the camp, the water is very difficult to control and no ore has been produced. At present, (June, 1912) a pump is being installed which is reported to be the largest so

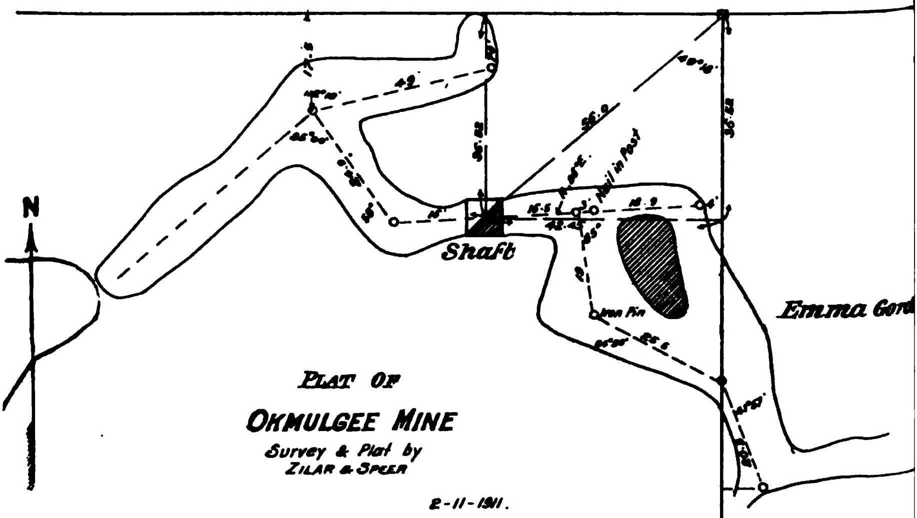


Fig. 13. Map of underground workings of the Okmulgee mine.

far installed in the Joplin district. It is hoped that this will handle the water and lower the level so as to permit the development, not only of this lease but of the other leases in this part of the camp.

Lying immediately west of the main run is a second run approximately parallel to it. The ore in this run is of the same general nature and occurs in the same conditions as that of the main run. The proportion of galena to sphalerite is somewhat less and there is less pyrite in the sphalerite concentrates. The Joplin-Miami, Queen City-Joplin, Okmulgee, and Little Maxine leases have been the principal producers from this run. The nature of the underground workings of the leases on this run is shown in the map of the underground workings of the Okmulgee mine (fig. 13.)

Still further west is a series of runs which are parallel to the main run but which are much shorter and narrower. The Golden Hen, Midas and Miami Yankee leases have produced considerable quantities of ore from the largest of these runs. On the Golden Hen lease the depth to ore is 130 feet, and the face of ore 14 feet. The run is 20 to 30 feet in width. The dirt contains about 8 per cent of concentrates, about ten times as much sphalerite as galena. The zinc concentrates average about 53 per cent zinc and 3 per cent iron.

The smaller runs to the southwest have not been successfully worked. The ore run is narrow and the dirt not very rich. The workings on the Donna (Southern Queen) and Consolidated leases are shown in figure 14.

No systematic drilling in search of deeper ore bodies has been done in the southwestern part of the camp.

PRODUCTION OF THE NORTHEASTERN FIELD.

The total production of the different camps in tons and its value from 1907 to 1911[33] is given below.

Quapaw camp.

Year	Galena	Value	Sphalerite	Value	Zinc carbonate	Value	Total production	Total value
1907	647	$43644	3062	$118400	97	$1631	3806	$163675
1908	504	26076	3539	109779	19	300	4062	136155
1909	244	12545	5015	207585	38	586	5297	220716
1910	270	13727	3921	152166	....	....	4191	165183
1911	329	18202	2245	82571	6	85	2580	100858

Miami camp.

Year	Galena	Value	Sphalerite	Value	Total tons concentrates	Total value
*1907						
1908	1730	$92177	6475	$139595	8205	$231772
1909	4056	210586	11569	361029	15265	571615
1910	3364	174134	10055	294877	13419	469011
1911	2848	152527	8391	247530	11039	400057

*Small production from one mine included in Quapaw camp.

33. Statistics from Mineral Resources of the United States, United States Geological Survey.

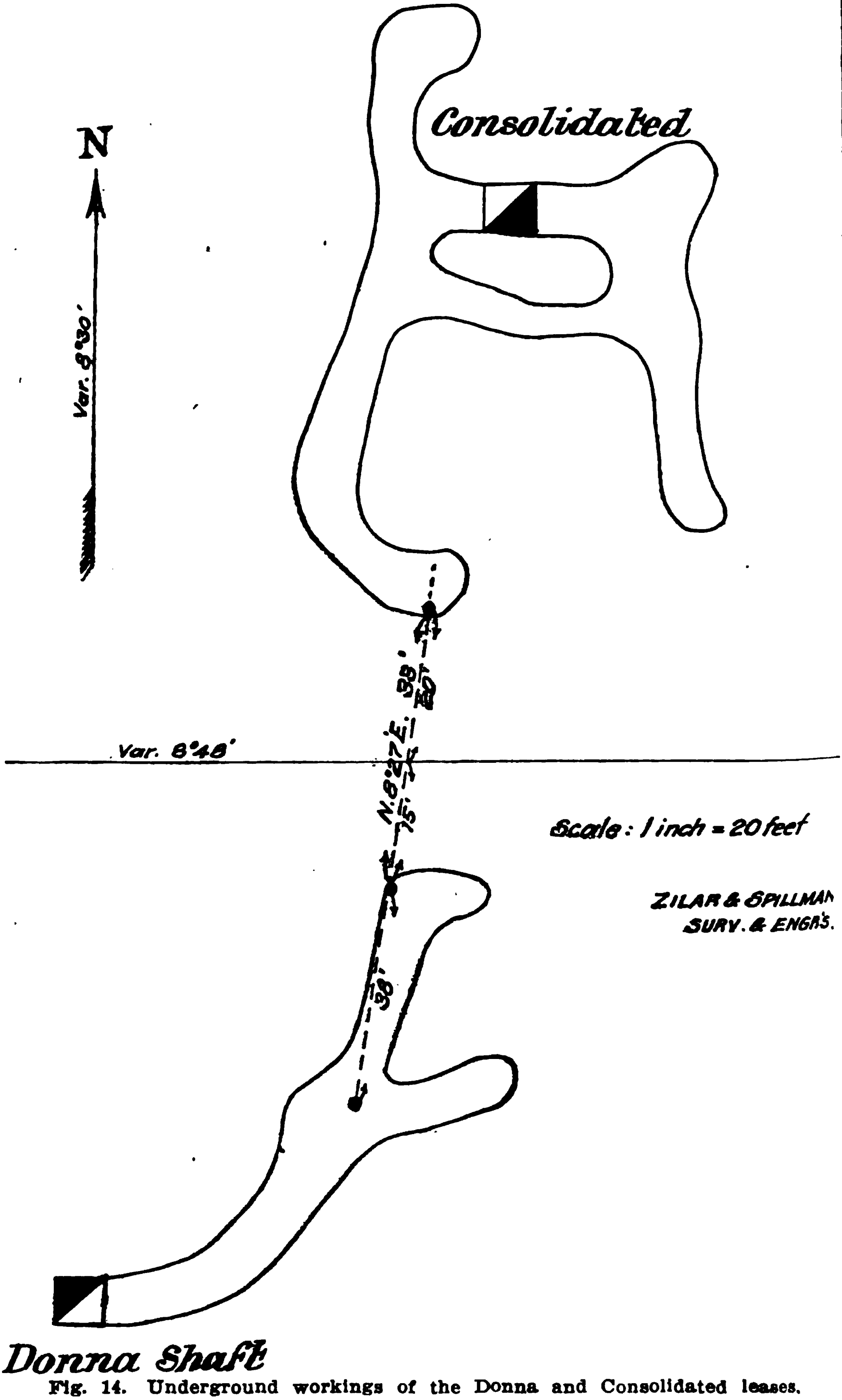


Fig. 14. Underground workings of the Donna and Consolidated leases.

Peoria camp.

Year	Galena	Value	Lead carbonate	Value	Sphalerite	Value	Zinc carbonate and silicate	Value	Total production	Total value
1907	15	$1157	5	$275	14	$568	583	$14036	587	$16006
1908	2	80	....	....	24	617	261	6325	287	7012
1909	6	246	....	....	....	....	267	7348	273	7594
1910	3	160	1	42	....	....	65	1406	69	1608
1911	12	628	....	....	....	....	311	8330	323	8958

OTHER OCCURRENCES OF LEAD AND ZINC IN NORTHEASTERN OKLAHOMA.

The Sycamore Creek District.

The prospects along the Seneca fault, which has been described under structure, are included in this district. These prospects were visited by Siebenthal in 1906 and as practically nothing has been accomplished since that time his description is given without further remarks:

"South of Seneca the Seneca fault cuts diagonally across the divide between Lost and Sycamore creeks, striking the latter 1½ miles west of the Missouri-Oklahoma line. At this point considerable prospecting has been done in and along the fault block, though without developing any paying bodies of ore. The first prospecting, which yielded some silicate, was done by means of a drift under the south bluff of Sycamore Creek a few feet above water level. Here the fault block is about 180 feet in width, and the throw is not sufficient to bring the sandstone of the Chester down to the present level of the surface. The limestones of the block, probably opened up more or less by the faulting, have been subjected to much solution, with the result that the space between the side faults, as exposed in the bluff, consists of a great mass of chert blocks lying topsy-turvy, the interstices being filled with tallow clay and residual clay. In the ravine just south of the bluff, near the southeast edge of the block, is a shaft from which drifts at the 75-foot and 104-foot levels extend southwestward for about 100 feet each. Thin ore was encountered in the lower drift, and better ore in the upper one. The ore consists of galena, sphalerite, and silicate. The silicate was too heavy to be separated from the sphalerite on hand jigs, and the ore could not be sold at a profitable price. Another shaft, 250 feet southwest of the deep shaft, encountered some large chunks of galena, which had to be broken up before they could be brought to the surface. Southwest of this point

the displacement by the fault is greater, and at a distance of 400 feet sandstone and sandy shale of Chester age are present to a depth of 65 feet, with some galena and sphalerite in crevices in the sandstone and in the secondary limestone cement of associated chert breccia."

Ottawa Prospects.

Some prospecting has been done near Ottawa, in SE. 1/4 sec. 36, T. 28 W., R. 23 E. NE. 1/4 sec. I. T. 28 N., R. 23 E. Galena and sphalerite are reported to occur under the same general conditions as in the Quapaw-Lincolnville district. No oxidized ores are found. One shaft has been sunk to 60 feet but no large body of ore is in sight at this horizon. Drill holes are said to show a disseminated ore carrying 2 to 3 per cent of concentrates, at a depth varying from 90 to 120 feet. The thickness of the ore is from 4 to 10 feet.

McCuddy Land.

Some lead and zinc has been obtained from pockets by shallow workings on the McCuddy land in sec. 14, T. 28 N., R. 22 E. To the end of 1911 over 35,000 pounds of galena and 10,000 pounds of sphalerite had been sold.

PROSPECTS FOR THE EXTENSION OF THE NORTHEASTERN FIELD.

All the commercial deposits of lead and zinc ore so far found in the Joplin district are intimately associated with the effects of the underground solution which took place between the deposition of the Mississippian rocks and the overlying Pennsylvanian shales. As has been noted the principal deposits are found in a basal "breccia" around old sink holes in the Boone which were filled by the Pennsylvanian shales. The effects of the inter-Mississippian-Pennsylvanian underground solution are found only to the northeast of a line passing through Miami, Wyandotte, and Tiff City, so that, in general, commercial deposits of ore are not likely to be found south and west of that line. Nothing in the geologic conditions of the area occupied by the outcrop of the Boone formation in Delaware, eastern Mayes, and northern Adair and Cherokee counties indicates the presence of lead or zinc in paying quantities.

The conditions at the Miami camp are different in some details from those in the other camps of the region. Here the principal ores so far worked occur in rocks of Chester age and the underground solution has acted upon the limestones lying immediately above the Boone chert.

The writer regards it as possible that the conditions at Miami may be duplicated at other localities along the contact of the Pennsylvanian

and Mississippian rocks for some distance to the southwest of the present productive region. The surface rocks give no indication of the location of areas affected by underground solution and therefore prospecting will be entirely a matter of chance and the chances for encountering narrow ore bodies like the one at Miami, even if they are present, which is by no means certain, will be very small. The prospects, then, for any great extension of the field are not at all favorable but if there is any such extension it will almost certainly be along the Missippian-Pennsylvanian contact to the southwest of Miami.

CHAPTER III.

OTHER OCCURRENCES OF LEAD AND ZINC IN OKLAHOMA.

THE ARBUCKLE MOUNTAIN REGION.

Location and Area.

The Arbuckle Mountains occupy an area 60 miles long and 10 to 30 miles wide in the south-central part of Oklahoma. The area includes southern Murray, northern Carter, the greater portion of Johnston, south-central Pontotoc, and a small portion of south-western Coal counties. The mountains are divided into two unequal portions by the Washita River.

Structure and Stratigraphy.

The Mountains consist of cores of granite, porphyry and associated igneous rocks all probably of pre-Cambrian age, surrounded by strata of paleozoic rocks dipping steeply away from the igneous cores. The simple dome structure is much complicated by minor folding and by thrust faulting which produces a typical Appalachian structure.

The section as exposed shows the following general succession of rocks:

Age.		
Pennsylvanian	Franks conglomerate (North of Mountains)	
	Glenn formation (South of Mountains)	
Mississippian	Caney shale	1600′
Mississippian (?)	Sycamore limestone	0- 200′
Devonian (?)	Woodford chert	650′
Siluro-Devonian	Hunton limestone	0– 300′
Silurian	Sylvan shale	60– 300′
Ordovician	Viola limestone	500- 700′
	Simpson formation	1200– 2000′
Cambro-Ordovician	Arbuckle limestone	4000– 6000′
Cambrian	Reagan sandstone	50– 500′
Archean	Tishomingo granite	——— ——-

The formations from the Reagan to the Caney were apparently laid down in a horizontal position over the granite, but in middle or late Pennsylvanian time were elevated into a dome and eroded. The Franks conglomerate and later Pennsylvanian rocks were deposited and still lie almost horizontally on the upturned edges of the older rocks.

Up to the present time the Arbuckle limestone and in less measure the pre-Cambrian rocks have been the only formations in which metallic minerals in notable quantities have been found and lead and zinc seem to be confined to the Arbuckle limestone. In view of this fact and also because the higher formations have no apparent connection with the origin or deposition of the ores the discussion will be confined to the Arbuckle limestone.

The Arbuckle limestone is exposed in three large areas in the Arbuckle Mountains as follows: (1) the major portions of Tps. 1 N., and 1 S., in Rs. 5 and 6 E., and smaller portions of the townships surrounding these; (2) an area of about one and one-half square miles in the southern part of Tps. 2 and 3 S., R. 5 E.; and (3) west of Washita River, a roughly triangular area consisting of the south part of T. 1 S., in Rs. 1 E., and 1 W., and the northern parts of T. 2 S., in the same ranges and the central portion of T. 2 S., R. 2 E.

The description of the formation as given by Taff[34] is as follows:

"Beginning at the base there are thin-bedded siliceous limestones 50 feet thick. There is a gradual change upward from these thin beds into the succeeding member, 300 to 400 feet thick, which consists chiefly of heavy-bedded dull-bluish and cream-colored dolomites. Many of these massive beds are indistinctly bedded and weather into very irregular brown and sometimes nearly black bowlders. Others are more crystalline, marble-like and of pinkish or gray colors. Succeeding these come about 250 feet of thin-bedded granular limestone and compact blue limestones which pass gradually into the main body of the formation, consisting of 3500 to 4000 feet of massive, compact magnesian limestone, the lower half of which contains chert in places. These limestones on weathering usually present smooth white surfaces of practically the same color as the fresh rock. As the top of this thick member is approached the limestone beds become less magnesian and thinner and are succeeded by the highest member, which is composed of limestone interstratified with occasional sandy beds and strata of red, yellow, and green clays."

The age of the Arbuckle limestone has hitherto been expressed by the term Cambro-Ordovician. In his new classification, Ulrich[35] places the upper half of the formation as certainly the age of his Canadian system, while the basal 700 feet is regarded as late upper Cambrian. Above this portion comes 400 feet of pink and white marble interbedded with massive cream-colored, black-weathering dolomite that is probably Ozarkian if that system is represented in the section. Succeeding this is a thickness of 2000 feet of massive, interbedded pure and magnesian lime-

34. Tishomingo folio (No. 98), Geol. Atlas U. S., U. S. Geol. Survey, 1903, p. 3.

35. Bull. G. S. A., vol. 22, p. 641.

stone in which no fossils have been found but which are lithologically similar to the succeeding 2300 feet which contain Canadian fossils and are therefore regarded as probably Canadian but possibly as Ozarkian.

The Davis Zinc Field.

While a great deal of the area underlaid by the Arbuckle limestone west and south of the Washita River has been prospected for minerals, the only area which has been developed to any extent or which gives any immediate prospect of such development is that known as the Davis zinc field.

Geologic conditions. The portion of the Arbuckle Mountains west of the Washita River is composed of a porphyritic granite core which forms two hills known as the East and West Timbered Hills, with the Reagan sandstone, the Arbuckle limestone and the younger formations dipping steeply away from these granite outcrops. Along the east side of East Timbered Hills the Reagan is faulted out and the Arbuckle is in contact with the granite.

The productive horizon is the member of the Arbuckle limestone which is composed of marbles and dolomites and which is regarded by Ulrich as probably representing his Ozarkian system. The whole outcrop of this member is called the "mineral belt" and is all claimed to carry various minerals in considerable quantities by some of the prospectors of the district but so far only a small area in secs. 17, 18, and 21 in T. 1 S., R. 1 E. has been proven to bear any metallic minerals in commercial quantities and sphalerite and smithsonite are the only valuable minerals so found.

The dolomites and limestones in this area dip to the northeast generally at from 40° to 50° but this general dip is considerably complicated by minor folding and by faulting. Several minor faults cross the outcrop at about right angles to the strike. The displacement of these faults varies from a few feet to 20 rods and in all observed cases the block on the northwest side of the fault is displaced to the east. All the rocks are very much broken by jointing but this is especially true of the dolomite. A sharp blow of the hammer breaks a large block into small angular fragments very few of which are over one inch in any dimension. The concentration of the zinc in the dolomite is probably due to this broken condition, the small seams forming channels for the passage of circulating waters carrying zinc in solution and at the same time affording small cavities for the deposition of the ore.

Nature of the ores and associated minerals. In this region the zinc ore occurs as the carbonate from the surface to a depth of 5 to 8 feet. Below this level the zinc is in the form of the sulphide, sphalerite or zinc blende. The carbonate contains large proportions of dolo-

mite. The blende is usually finely disseminated but in some cases seems to have largely replaced the country rock in irregular masses which are confined to the dolomite layers so that the blende makes up the larger portion of some of the strata. The largest mines that have been opened, the Hope-Sober, the Ben Frankin mine of the United Mine and Milling Company, and the Goose Nest mine of the Arbuckle Mining and Milling Company, show two layers of the blende bearing rock each 3 to 4 feet thick separated by a layer of "dead rock," 5 to 6 feet thick, carrying only thin seams of blende. A well drilled on the property of the United Mining and Milling Company is said to have shown the rich ore to a depth of 30 feet and to have encountered a similar body 15-20 feet thick at 125 feet below the surface.

The prospectors of the region report very good assays on material from practically all the prospect holes, although the appearance of the material does not indicate that much metallic material is present. Analyses of surface samples of carbonate showing as high as 47 to 50 per cent zinc are commonly reported and approximately average sample of blende ore are reported as showing 58 to 60 per cent zinc. However, the highest assay reported on a carload of blende ore is 38.5 per cent zinc.

Some of the samples collected by this Survey show the following results: Four samples consisting of chips from surface blocks in different parts of the field show respectively, trace; .17 per cent; .77 per cent; samples of carbonate from near the surface and from shallow prospects in different localities show respectively.55 per cent, .45 per cent, .77 per cent, and 5.4 per cent. A sample composed of chips of a large number of blocks in a pile of blende ore selected for milling show 25.46 per cent ; a sample of blende from one of the deeper prospects shows 8.88 per cent; a sample from all parts of one of the most widely advertised mines shows 8.08 per cent. The concentrate from the only mill which has been installed shows 45.96 per cent. The mill was not run long enough to get the tables and grinding machinery properly adjusted so that the showing of the concentrate is probably not so good as can be obtained.

Other metals occur in small quantities with the zinc. An interesting feature is a narrow belt of iron ore (hematite) seldom over one rod in width, which lies near the middle of the dolomite member throughout the length of the outcrop. Bowlders of hematite, in part altered to limonite, are strewn thickly along the surface of this belt. Some of them are as much as 10 feet in diameter. In only a few cases does the iron ore extend as much as 10 feet beneath the surface. The richest portion of the zinc ore so far seems to be in close proximity to this iron-bearing horizon.

The cause of this segregation of the iron ore into so narrow a belt is problematic but it is entirely possible that it is due to a small fault

parallel to the strike of the rocks. Such a fault would be almost impossible to trace in the dolomite unless the belt of ore itself be taken as evidence of its existence. The localization of the ore took place before the formation of the small faults perpendicular to the strike previously mentioned since the iron ore belt is offset by them.

Pyrite is practically absent from the zinc blende in the body of ore near the surface. The cuttings from the deep body encountered in the well previously mentioned show some pyrite but it is apparently in small quantity.

Lead occurs in small quantity very near the surface as the sulphide and as the carbonate or sulphate. It is absent from the deeper ore and has not been observed in sufficient quantity to make its separation profitable. Copper stains are often present and some pieces of malachite and azurite have been discovered in different parts of the field. So far no large body of copper ore is known to have been found although there are rumors to the effect that such bodies exist. Yellow stains of greenockite, cadmium sulphide, are common on the rock and ore near the surface.

Present development. The development in the Davis field at present consists principally of shallow prospect holes, of which there are a great number scattered over the hills, especially in the region east of the East and West Timbered Hills.

In two localities steps toward further development have been taken. Immediately east of West Timbered Hill the United Mining and Milling Company has erected a 4-table mill at their Ben Franklin mine near the center of sec. 21 T. 1, S., R. 1 E. The machinery is on the ground to erect a 4-table mill on the Arbuckle Mining and Milling Company's property in the SW. ¼, sec. 17, T. 1 S., R. 1 E. In the NW. ¼ sec. 18, T. 1 S., R. 1 E. the Rumley or "Incline" mine consists of an inclined shaft or tunnel. The track in the tunnel dips at about 20° to the southeast, while the rocks dip at 30° to 35° to the north. In the summer of 1911 the tunnel had reached a length of about 150 feet. A sample selected from the dump was analyzed but showed no metallic value.

Some prospecting has been done two miles east of East Timbered Hill. One drill hole 160 feet deep is reported to have encountered a body of ore 14 feet thick at a depth of 67 feet, which shows 19 to 26 per cent of sphalerite, and another body 27 feet thick at 140 feet which is also very rich. The writer has not seen any cuttings from this hole and the authorities for the analyses are not known to him.

One great hinderance to the development of the filed is the lack of adequate water supply for milling operations. The best prospects are situated on the divide between Colbert and Honey creeks, and the small

branches flowing into these streams do not carry any water during the greater part of the year. The mill at the United Mining and Milling Company's mine was idle almost all of 1911 on account of lack of water.

Prospects for future development. Although there is undoubtedly considerable ore present in the field there are several factors which combine to make the value of the field somewhat problematical and to render any prophecy along this line a matter of guess work. Some of those factors are as follows:

1. The question as to the extent of the ore. While the prospectors admit that the richest ore is near the outcrop of iron ore which has been described, they claim that good values are present practically to the edges of the dolomite outcrop. The samples so far collected from prospect pits near the edges of the dolomite and analyzed in the Survey laboratories do not bear out this claim but the number of samples collected is too small to warrant a definite conclusion.

2. The depth to which ore occurs. The first body of ore does not exceed a depth of 40 feet over most of the area which has been the most thoroughly investigated. The only investigation at a greater depth than 50 feet is the well which has been mentioned. Some ore was found at about 125 feet, but neither the exact thickness nor the percentage of zinc was accurately determined. Thorough prospecting by drilling is the only methods of settling this question and until this is done, any statement as to the probable value of the field must be founded on mere supposition.

3. The absence of pyrite is favorable to the production of concentrates very low in iron, but on the other hand the extreme fineness of grain of much of the ore will render complete separation very difficult and the concentrates will probably run high in lime.

4. The question of adequate water supply is unsolved. The portion of the region which is being developed lies near the headwaters of a small creek and there is not sufficient water through most of the year to supply the one concentrating mill already installed. The limestone and dolomite are too badly fractured to form a reservoir for any water which might be impounded during the wet season. The problem may be solved by the deep wells which are proposed, but the high dip of the rocks, the small catchment areas, and the presence of numerous sinkholes renders it improbable that an adequate supply will be encountered at a reasonable depth. A possible solution is to pipe water from Honey Creek near Turner's Falls. The distance is about 4 miles from the mines in section 18, and the mines are approximately 250 feet above the creek. Water for the northern portion of the field can probably be secured from Colbert Creek, about 2 miles below the stream from the mines.

5. The ore or concentrate must be hauled to Davis, a distance of 7 miles over roads which at present are very bad. This of course is not prohibitive, but should be borne in mind in trying to arrive at any estimate as to the value of the field.

WICHITA MOUNTAIN REGION.

The Wichita Mountain group lies to the northwest of the Arbuckles and extends from Lawton on the southeast to Granite on the northwest a distance of 65 miles. The mountains are 30 miles wide at the middle and narrow rapidly toward both ends. They are divided into groups known as the Wichita, Quana, Raggedy, and Devils Canyon mountains.

The Wichita Mountains include the largest area and are composed principally of a medium to coarse-grained pink to red granite. The Quana Mountains are principally of porphyritic granite; the Raggedy Mountains are isolated peaks of anorthosite, black and gray granite, gabbro and diorite; and the Devils Canyon Mountains to the west consist of peaks of medium to coarse grained red and pink granite.

The general structure of the group is apparently the same as that of the Arbuckle Mountains, but the Redbeds more nearly covered the Wichitas than they did the Arbuckles and the great series of paleozoic sedimentaries which surround the Arbuckles are buried under the Redbeds, except for an outcrop of the Reagan sandstone and a range of hills of Arbuckle limestone along the north side of the mountains, and three knobs of Viola limestone near Rainy Mountain Mission.

No metallic minerals have been reported from the Arbuckle limestone of the Wichita Mountain region but a great deal of time and money have been spent in prospecting the various areas of igneous rocks.

All of the granites are cut by dikes of varying composition, but principally of a basic nature. The dike rocks are usually fine-grained and green to black in color. In general the contacts of the dikes with the granite or gabbro country rocks are very sharp and show very little or no mineralization. The igneous rocks are manifestly much older than the oldest sedimentary rocks of the region which are Middle Cambrian (Upper Cambrian of Ulrich). They are therefore almost certainly pre-Cambrian and from the nature and relation of the rocks are more probably Archeozoic than Proterozoic (Algonkian). The coarse-grained character of the granites and gabbros indicates that they were formed at considerable depths below the surface. It seems, therefore, that the granites now at the surface were intruded into pre-existing surface rocks and were later cut by the dikes, and that all the activity took place long before the beginning of the Cambrian. The rocks into which the granites were intruded and which must have formed a great

thickness above the present surface, were then eroded during the long interval before the deposition of the Reagan sandstone in middle Cambrian times. If there was any mineralization by hot solutions from the granites or dikes, it must have taken place in the rocks nearer the surface, which were eroded before the deposition of the Reagan.

The geologic conditions, therefore, are not such as to lead to the expectation of finding notable deposits of metallic minerals in the igneous rocks of these mountains and so far the developments have been in line with the indications of the geologic conditions. Thousands of dollars have been spent in prospecting in this region and so far there has been no return. Hundreds of prospect holes may be found in the mountains, most of them along the dikes but some of them in the ordinary granite or gabbro country rock where there is no indication whatever of metallic minerals.

Prospecting was extremely active after the opening of the country to white settlers and great excitement resulted in 1902. In October, 1903 the region was visited by H. Foster Bain of the United States Geological Survey who visited many prospects and collected samples from the prospects, 71 of which were assayed in the laboratory of the Survey at Washington. Of these 71 were assayed for gold, 10 for silver, 2 for copper, and one for lead. No trace of gold was found, two samples showed 0.14 and 0.92 ounce per ton of silver, respectively; the two samples assayed for copper gave 0.35 and 10.81 per cent respectively, and the sample assayed for lead gave 3.36 per cent. The sample showing 10.81 per cent copper was picked material from a vein about one and one-half inches wide.

The claim from which the sample showing 3.36 per cent lead was collected is located in sec. 16, T. 3 N., R. 14 W. It is described as follows by Bain[36]:

"CLARK AND BENNET MINE.

"This is also known as the Galena mine. It is located a short distance northwest of the Gem and Diamond mines, and shows a greenstone dike about 2½ feet thick cutting through the red granite. This dike has been faulted and considerably broken up. There has been a development of white quartz in the interstices of the broken rock. Accompanying the quartz is galena and some chalcopyrite. The sample taken from here (W-48) was from the dump and represented the best material which could be found. It showed on assay, as noted below, no gold, 0.92 ounce of silver, and 3.63 per cent of lead. The silver value is unimportant. The lead is not enough to give the material rank as an ore. In its present form and in order to make mining pay, it would be necessary to

36. U. S. G. S., Prof. Paper. No. 31.

erect concentrating machinery and produce an ore carrying a larger amount of lead. The development work so far accomplished does not show enough lead to warrant this, and while the matter is one of personal opinion, it is not believed that further development work would give any better results."

The conclusions which were reached by Bain in regard to the mineral possibilities are as follows:

"In view of the precautions taken in collecting the samples, and the great care with which they were assayed, the absolutely uniform absence of even a trace of gold and only the occasional presence of a small quantity of silver, copper, or lead allows but one conclusion to be drawn. namely, that none of the prospects examined shows any ore in the proper sense of the term, nor does any one of them have any present or probably future value. The possible exceptions in the case of copper and lead have already been discussed in detail.

"Whether future prospecting may reveal other occurrences which do have value cannot, it is true, be stated. It is believed, however, that the prospects examined were fully representative and have, in many cases at least, been developed enough to allow a proper judgment as to their value to be made, and in no case do they offer any encouragement whatever for additional prospecting.

"In the granite mountains near Lugert there are certain coarse pegmatites showing crystals of quartz 3 inches or more in length. With the quartz crystals are some small, black, semi vitreous crystals recognized by Doctor Hillebrand as belonging to the columbite-tantalite group. It is hoped that further investigations may show the presence of some of the rare earths.

While the results of the investigations were disappointing in so far as they failed to show the presence of the expected ore bodies, the region is one of other valuable resources. The granite, which is so abundant, is suitable for building purposes, and is at many points excellently situated for quarrying. The limestones are available for the manufacture of lime and are of suitable composition for the manufacture of Portland cement if fuel and industrial conditions ever change so as to warrant investment in that industry. The small asphalt springs found near the east end of the Fort Sill Reservation are possibly indicative of larger deposits of oil and gas, and the excellent soil of the prairies and valleys, combined with good water resources, afford the basis for a large and thriving population."

A considerable amount of work has been done since that time but the conclusions reached have been borne out so far. No shipments of ore are known to have been made which have repaid expenses. Very

little development or prospecting is going on at present in the greater portion of the mountains but in a few of the more promising prospects some attempt at development is being made.

LAWTON AREA.

One of these localities is a few miles northwest of Lawton. On petition, these prospects were visited by D. W. Ohern, Director of the Oklahoma Geological Survey in March, 1912, and a report was made to the petitioners. This report is given in full:

General geology. "The region is underlain by complex series of igneous rocks, that is, rocks that were once in a molten state. These consist largely of a pink granite. This granite is widely exposed not only in the immediate region examined but throughout the Wichita Mountains in general from near Lawton on the southeast to Granite on the northwest, a distance of 50 miles. The rock is always hard and compact and is therefore very difficult to work in.

Intruded into the pink granite are numerous masses of dark rock (usually called trap) which varies considerably in mineral composition and texture from place to place. But the variations are not important. The bodies of this rock are also extremely variable in size. Some are only an inch or two, or even less, in width while others are several hundred yards wide or even more.

Quartz stringers are very common in the entire region especially in the granite. These are very small, few exceeding a half inch or an inch in width. The granite hills are in many places stripped clear of all soil and rock debris, and such places offer excellent opportunity for observing the stringers. They are observed to run for short distances and then thin out, others often appearing and then likewise disappearing.

The best observations lead me to the firm belief that faults are common. Faults are fractures or breaks in the rocks, along which movement of rocks has taken place.

There are several zones along which the rock is badly weathered, or rotted so to speak, to a considerable depth. In other places small streams run along the zone made weak by the breaking of the rocks. Without doubt these faults play an important part in the origin of the ores.

Prospects examined. Very much to my regret, it was impossible for me to enter all the various prospect shafts. This was owing in part to the presence of water and also to the fear of encountering gas. Only one of the prospects visited is being worked and in this only was I able to go to any depth. So that this report is not as full as is desirable on my part.

The Starley Mine. This prospect was examined pretty thoroughly and numerous samples taken from which assays were made. The shaft at present is down about 70 feet deep. All drilling is being done by hand, and is an extremely slow process, the only rock encountered being the pink granite which is very hard.

The foot wall is here rather sharply defined, being evidently formed by a fault. Some mineralization has taken place in the country rock on the foot wall, but it is too slight to be considered. On the hanging wall the pink granite has been mineralized in some places to a considerable extent. The massive granite is impregnated chiefly with galena, this being the only mineral visible to the naked eye with the exception of small amounts of iron sulphide. Several samples taken at various depths gave the following assays, lead being the only metal determined except in No. 7:

	Lead.
No. 1, 5 ft. from surface	3.32%
No. 2, 12 ft. from surface	3.11%
No. 3, 22 ft. from surface	3.84%
No. 4, 34 ft. from surface	4.87%
No. 5, 44 ft. from surface	12.45%
No. 6, 65 ft. from surface	12.87%
No. 7, 70 ft. from surface	5.86%; gold $.85

silver tr.; copper none; zinc trace.

These assays show a downward enrichment of the ores which is a good omen. The last assay seems to be an exception but does not in my judgment detract from the other values. If the last of the assays be taken as the average, lead is the only thing to be taken into account. But when other things are considered the assays give but little promise.

As already noted the shaft is being sunk in the granite. The expense connected with mining this impregnated rock is very high. In some places the feldspar of the granite is almost entirely lacking so that the mass of the rock is made of quartz. This makes the work even more difficult.

An all important factor here, as in similar cases, is the amount of ore in sight. This cannot be determined with anything like precision. At present the ore body is exposed for about 6 or 7 feet from the foot wall. There is no way of ascertaining further measurements.

Should extensive work be undertaken water will soon become an important matter. There is very little near at hand and certainly not enough for jigging if the process should be instituted.

Should the ore be hauled to railway it will be rather expensive as is evidenced by the condition of the road in the first 3 of the 8 miles to

shipping point. Hauling under these conditions will cost at least $2.00 a ton.

If operations should be undertaken by machinery, the source of power is important. There is some wood near at hand but it would be unsatisfactory as a fuel as experience in other similar regions has shown. Coal would have to be hauled 8 miles by wagon. No water power is to be had in the immediate vicinity. Probably the most satisfactory source of power would be had by installing a dam at some of the sites in Medicine or Cache creeks and converting the power into electricity, transporting the same by wires to the scene of mine operations.

When all these factors are considered it appears that the outlook for this prospect is not bright unless the ore body is much larger than present conditions indicate and unless there is a marked downward enrichment of the ores.

A few hundred yards north of the prospect just discussed lies another opening of but a few feet in depth. The site was evidently suggested by the presence of a fault which has caused a zone of rock 2 to 3 feet wide to become deeply weathered. The country rock here has been mineralized to a very small extent, a few very small masses of galena being visible. From what can be seen there is nothing to give warrant for further prospecting. No vein or lead is visible which would give promise.

Coal Lode. About one and one half miles west of Dr. Starley's prospect lies the Coal Lode prospect. At the time of my two visits this prospect was partly filled with water and hence I was unable to gather information upon which to base an opinion of very much value. The shaft has been sunk to a depth of 70 feet or more. On the dump is considerable material containing lead ore of some promise. Assay from such material however would be of no avail amounting to nothing better than a guess. It was impossible to ascertain exactly what is the nature and size of the ore body; but from the material on the dump I am disposed to think the prospect is very much like that of Dr. Starley, that is, that the country rock has been mineralized along a fault. I can give no opinion of the value of this property.

Copper Eagle Prospect. This prospect lies about five miles west of the Starley prospect. It is sunk to a depth of 70 feet in the hard fresh pink granite, no trap being directly associated. I examined carefully the walls of the shaft to some depth, being unable to go to the bottom on account of water and gas. The material on the dump showed some stainings of the green hydrous carbonate of copper (malachite) but no other evidence of ore was seen. It is difficult to understand why this was sunk here, there being, so far as I can see, absolutely nothing to give promise of encountering anything of value. There are no veins or

leads to be seen in the shaft that are not common to the region in general. I see no wisdom in pursuing this project further.

The American Girl. This prospect lies between the Coal Lode and the Copper Eagle. Here also water and gas prevented entrance into the shaft. I am informed that the shaft has been sunk to a depth of 170 feet. The material in the dump contains considerable jack (sphalerite) and it is not impossible that it may be and is found in paying quantities.

Of the prospects examined only the Starley, Coal Lode and American Girl show promise. In the first, unless the body of ore proves very large soon and unless the ore grows much richer downward, further work would be unwise on account, chiefly, of the very high cost of working in the country rock. As above stated, nothing definite could be learned concerning the Coal Lode and American Girl."

In regard to the Wichita Mountain region as a whole it may be said that there is little or nothing to indicate that it will ever be a producing region of lead, zinc, or other metals. A few small areas show some prospects of development but even in these cases the appearances are not altogether favorable and their future value is problematic.

THE OUACHITA MOUNTAIN REGION.

Many reports have been current as to the occurrence of lead in the Ouachita Mountains of southeastern Oklahoma. Most of these are based on stories of the Indians having obtained lead for bullets from some place in the region. So far nothing definite is known as to the localities in which it is supposed to occur and no samples from the region have been seen. The mountains consist of a great thickness of sandstones, shales, and cherts, ranging in age from Ordovician to Pennsylvanian. The only metallic mineral known to occur is manganese which occurs in small lumps and nodules in the Arkansas novaculite (upper part of Talihina chert) of Ordovician age. So far no bodies of sufficient size to serve as an ore of manganese have been found. The formations exposed in this region have been pretty thoroughly prospected in Arkansas and no metallic deposits of value have been found. This is, of course, not to be taken as proof that there are no such deposits in the rocks of Oklahoma, but it renders their occurrence improbable, since, so far as can be seen, the conditions are altogether similar in the two states.

MINOR OCCURRENCES.

Samples of a sandstone with disseminated crystals of galena have been sent to the Survey office from Ada and the same material has been on exhibit in the Mineral Building at the State Fair. From the appearance of the material it should be easily worked and probably contains

sufficient lead to make it profitable, if it should occur in sufficient quantities. So far as is known, however, the amount available is small, although detailed work in the locality may reveal commercial deposits.

Lead or zinc or both have been reported from a great many other localities in the eastern part of the State and several very rich samples have been sent to the Survey office for identification. In every instance the mineral, usually galena, is of the type and appearance of that from the Joplin region and can usually be traced to that locality. Many of the inhabitants of eastern Oklahoma have visited the Joplin field and have brought samples back with them. These specimens lie around until their true origin is forgotten, or are lost and then found by parties who do not know their origin, and are regarded as indicating large bodies of ore in the immediate vicinity. While it is not impossible that workable deposits of lead and zinc may be found in other localities it is fully believed that the localities previously discussed, viz:, the extreme northeastern corner of the State, the Arbuckle and Wichita Mountains and possibly the Ouachita Mountains, are the only ones in which there is a reasonable expectation of finding either lead or zinc in commercial quantities.

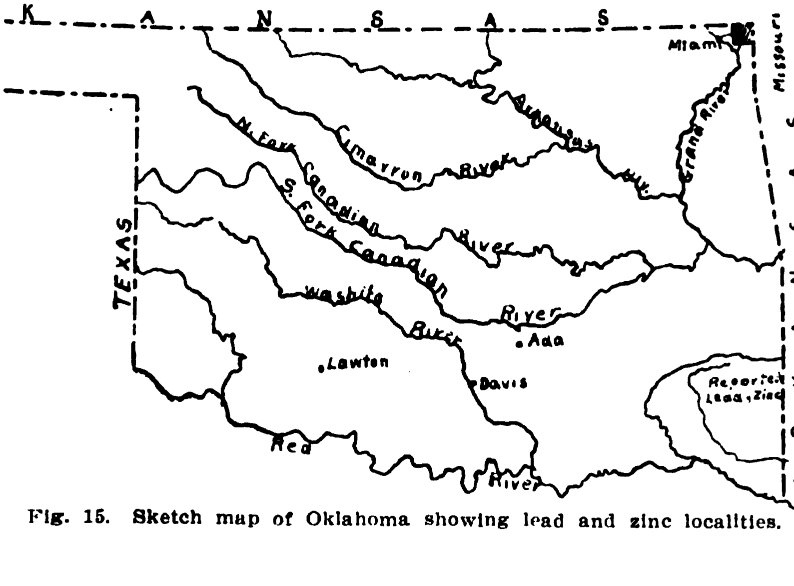
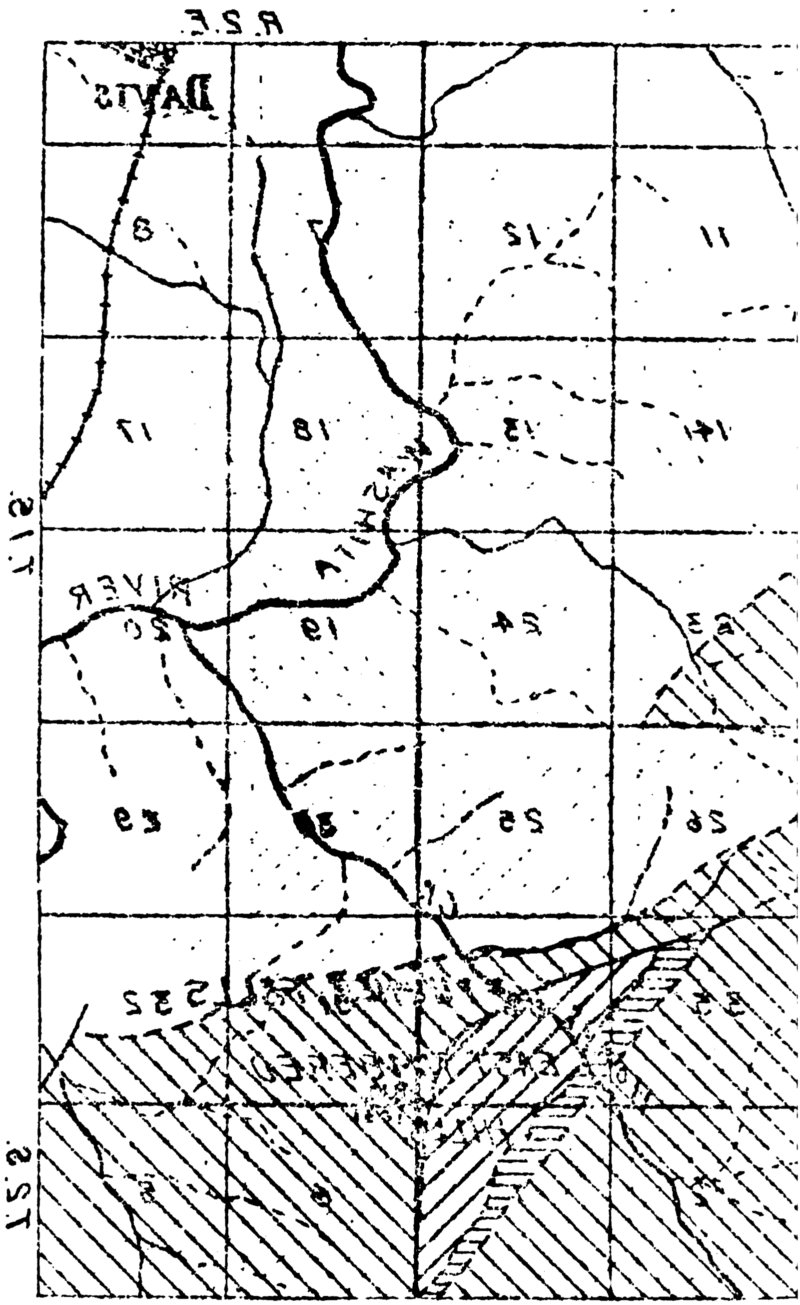


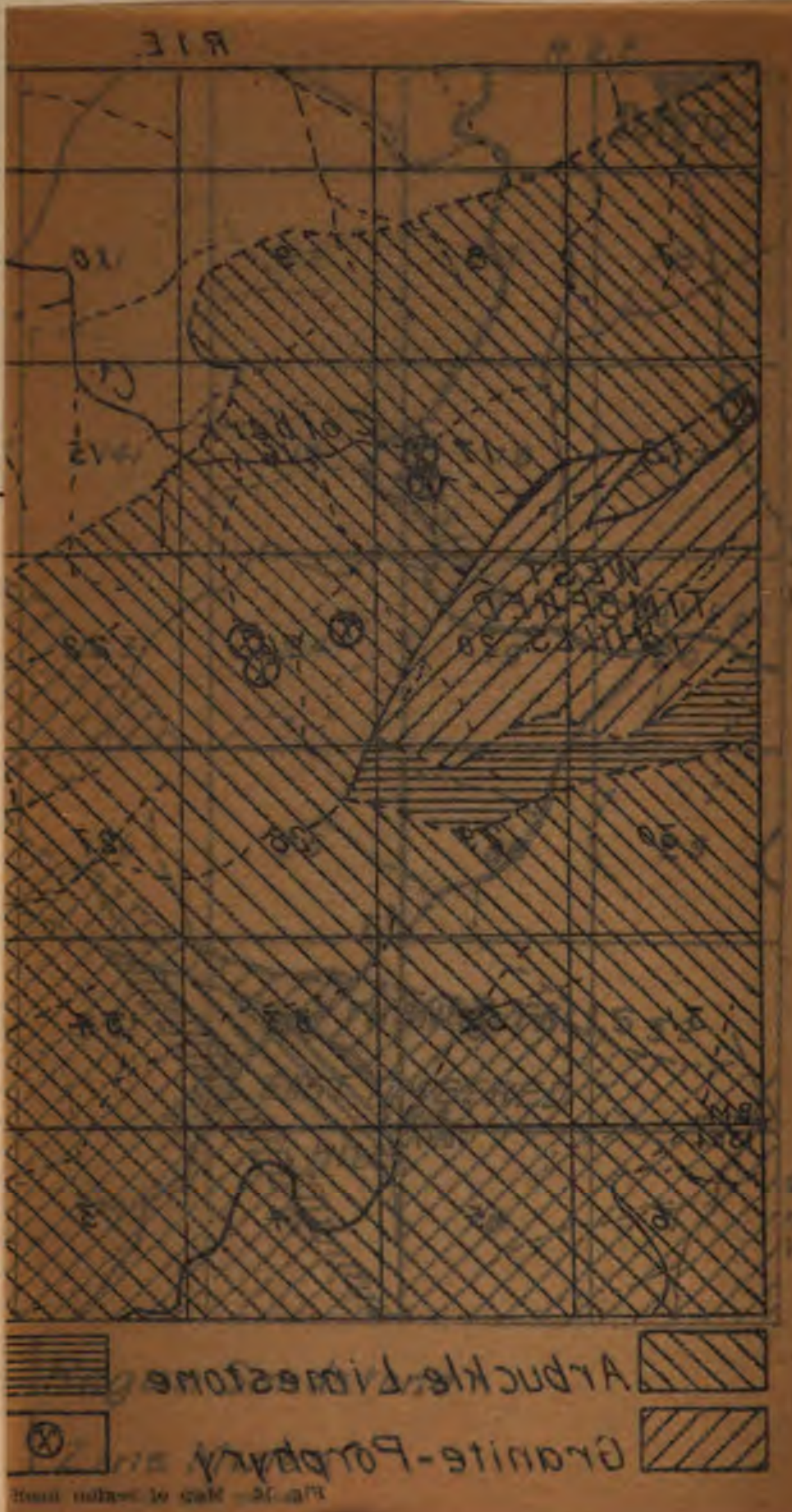
Fig. 15. Sketch map of Oklahoma showing lead and zinc localities.



Regan Sandstone

Zinc Mines

wing zinc mines.


Arbuckle Limestone
Granite-Porphyry

OKLAHOMA GEOLOGICAL SURVEY

Governor Lee Cruce, State Superintendent R. H. Wilson,
President Stratton D. Brooks, Commission

D. W. Ohern, Director
L. C. Snider, Assistant Director

BULLETIN NO. 10

THE GLASS SANDS OF OKLAHOMA

By FRANK BUTTRAM

NORMAN
JANUARY, 1913

SCIENTIFIC STAFF

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INTRODUCTION.

This report is based on field work carried on by the writer during 1911 and 1912 under the direction of the Oklahoma Geological Survey, and on subsequent chemical and physical analyses made in the laboratory of the survey. In the work in the Arbuckle Mountains the writer availed himself of Taff's[1] and of Reed's[2] investigations. In the Tahlequah region free use has been made of Taff's investigation[3]. In the study of the Trinity sand the author has had access to the dissertation of Pierce Larkin in the Library of the State University of Oklahoma dealing with the Cretaceous area of the southeastern part of the state.

In the present report a general discussion of the glass sand industry will be given, this to be followed by a detailed account of the distribution and character of the glass sands of Oklahoma, which are adapted to and available for glass manufacture.

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1. Taff, Jos. A., Preliminary report on the geology of the Arbuckle and Wichita mountains: Prof. Paper, U. S. Geol. Survey, No. 31, 1904.

2. Reeds, C. A., A report on the geology and mineral resources of the Arbuckle Mountains: Bulletin Oklahoma Geol. Survey, No. 3, 1910.

3. Taff, Jos. A., Tahlequah folio (No. 122), Geol. Altas U. S., U. S. Geol. Survey, 1905.

CHAPTER I.

GENERAL CONSIDERATION OF GLASS AND GLASS SAND.

HISTORICAL.

Glassmaking is one of the oldest industries, there being good reason to believe that it dates far back in the development of civilization, probably antedating the brickmaking industry. The earliest evidence of the manufacture of glass has been found in Egypt where archaeologists have discovered sculptured designs representing glassblowers at work. The evidence is that these designs date as far back as 4000 B. C.

Although the Phoenicians are accredited with the discovery of the methods of glassmaking, the majority of authorities are of the opinion that this honor belongs to Egypt since the most ancient relics of the glass industry have been found in that country. Pliny, however, writes that the discovery was made by a group of Phoenician merchants returning by ship from Egypt to Syria with a cargo of natron (crude soda). Overtaken by a storm, they landed on a sandy beach at the mouth of the river Belus, which flows from Mount Carmel into the Mediterranean Sea near Tyre and Sidon. While cooking their food they supported their cooking utensils on blocks of natron. This material acted as a flux and the fire melted the sand. This story is probably a pure fable, as such results under these conditions are impossible. There is little doubt, however, that the discovery of the methods of making glass was purely accidental, but the discoverer, and the time and place of the discovery are absolutely unknown.

The advancement which has been made recently in the process of manufacture of decorated glass is not as real as it seems; for the Egyptians were acquainted with the art of pressing the glass while hot into metallic molds—a feat which was performed as succesfully then as it is in modern times. Archaeologists have taken from Egyptian tombs glass coins on which have been impressed figures of deities and various sacred emblems, the glass being colored to imitate precious stones.

As nearly as can be learned, the glass industry lived and thrived until the overthrow of the Roman Government by the Barbarians from the north, when the glass industry suffered the fate of nearly all the other industries. During the dark ages one branch of the industry—the making of mosaics and stained glass—was perpetuated by the church. Not until the nineteenth century, however, did the art of glassmaking begin to emerge from the almost total eclipse it had experienced and to this century most of the improved methods which have placed it once again among the arts must be assigned.

DEFINITION OF GLASS.

According to Bizer[4] "Glass is a transparent solid formed by the fusion of siliceous and alkaline matter, which assumed while passing through said state of fusion at a temperature sufficiently high, a fluid condition, and, as the temperature falls, passing from the fluid through a ductile viscous state to a solid,—devoid of crystaline structure, impervious and impenetrable to both gases and liquid fluids—a hard, brittle mass which exhibits, when broken, a lustrous fracture."

This definition shows clearly how difficult it is to frame an exact definition of glass from a chemical standpoint, because no one of the several varieties has definite chemical composition; but still the fundamental constituents of all commercial glass are very similar.

COMPOSITION OF GLASS.

The chief raw constituent of glass is quartz sand which, when pure, is composed of silica (SiO_2). After fusion the glass consists of a mixture of two or more silicates united into a homogeneous, hard, brittle mass. The variety or character of the glass is determined by the proportion and molecular composition of these silicates. In the process of manufacture the silicates are formed by the union of the silica with potash, soda, lime, lead, and other bases. Other ingredients are sometimes added in small amounts for special purposes, such as deoxidizing and decolorizing agents, and for imparting special colors and properties to the silicates.

For the formation of a silicate it is necessary that at least one alkali base be present to combine with the acid

4. Bizer, Benjamin F., Elements of glass and glass making, 1899, p. 7.

radical silica. The quantities of the various constituents are made to vary according to results desired. These proportionate quantities are determined by experiment and so the formulae for the various varieties of glass are established. Although a close approximation of the relative amounts of silica and added bases in the several varieties of glass may thus be made, yet in several samples of the same variety the chemical composition may vary within comparatively wide latitude, so that it is quite impossible to classify the several varieties on the basis of their chemical composition.

CLASSIFICATION OF GLASS.

Commercial usage has established four general classes of glass, viz:

1. Plate glass, comprising rough plate, rolled plate, ribbed plate, and polished plate.

2. Window glass, including ordinary and colored, or painted, sheet glass.

3. Flint glass. This term has an extensive application and includes all common (or lime), flint, and crystal glass.

4. Bottle glass. This grade is coarse and inferior in quality. It is used extensively in the commonest grades of bottles and other hollow ware. It is usually of a greenish, amber, or black color.

The approximate composition of these grades of glass is shown below:

Analyses of plate glass.

	FRENCH		ENGLISH						
	St. Gobain. Peligot.	French. Dumas.	Chances. Benrath.	British Plate Glass Co. (Mayer & Brazier.)	London and Thames. (Mayer & Brazier.)	Belgian. Charlerol. Benrath.	German. Jaeckel.	Hanoverian. Emmerling.	Venetian. Berthier.
Silica	73.00	75.90	70.71	77.36	78.68	73.31	72.31	73.79	68.60
Soda	11.50	17.50	13.25	13.06	11.36	13.00	11.42	13.94	8.10
Potash	....	....	....	3.01	1.34	....	....	0.60	6.90
Lime	15.50	3.80	13.38	5.31	6.09	13.34	14.96	8.61	11.00
Magnesia	....	....	....	....	....	....	....	0.12	2.10
Manganese	....	....	....	....	....	....	....	0.32	0.10
Sesqui-oxide of Iron....	....	....	1.92	0.91	trace	0.83	....	0.68	0.20
Alumina	....	....	....	trace	2.68	....	0.81	0.58	1.20

Analyses of window glass.

	French. (Dumas)	English. (Dumas)	Chance's. (Cooper)	Russian. (Benrath)
Alumina	7.60	69.00	71.40	71.27
Silicia	68.00	11.10	15.00	20.10
Soda	10.10	12.50	12.40	8.14
Lime	14.30	7.40	0.60	

Analyses of lead glass.

Glass	Analyst.	Silica.	Soda.	Potash.	Lime.	Lead.	Iron.	Alumina.
English crystal	Faraday	51.93	.....	13.67	.....	33.28	.....	.....
" "	Berthier	59.20	.....	9.00	.....	28.20	0.40	.....
French crystal	Sauerwein	48.10	.....	12.50	0.60	38.00	0.50	.....
" "	Benrath	50.18	.....	11.62	.....	38.11	1.30	1.30
American crystal	Fletcher	53.98	6.71	7.60	.....	29.78	1.93	1.93
" "	"	54.12	5.58	7.98	.....	31.27	1.05	1.05

Analyses of lime glass.

Glass	Analyst	Silica.	Soda.	Potash.	Lime.	Magnesia.	Manganese.	Iron.	Alumina.	Baryta.
French	Pelouze	72.10	12.40	.....	15.50	.....	.....	.....	.....	.....
" tubes	Berthier	69.20	3.00	15.80	7.60	2.00	.....	0.50	1.20	.....
Bohemian	Rowney	73.13	3.07	11.49	10.43	0.26	0.46	0.13	0.30	.....
American	De Brunner	71.92	14.55	.....	5.14	2.04	.....	.....	6.22	.....
"	Henrivaux	70.40	9.13	8.66	10.00	.....	0.50	0.02	0.99	.....
"	Benrath	67.10	10.30	4.20	5.10	.....	.....	0.10	0.30	11.90

Analyses of bottle glass.

Kind of Glass.	Analysts	Silica.	Soda.	Potash.	Lime.	Manganese.	Sesqui-Oxide of Iron.	Alumina.	Magnesia.
French..... Sauvigny ...	Berthier	60.00	3.10	3.10	22.30	1.20	4.00	8.00	.....
St. Etienne...	Berthier	60.40	3.20	3.20	20.70	....	3.80	10.40	.....
Epinac........	Berthier	59.60	.....	3.20	18.00	0.40	4.40	6.80	7.00
Sevres........	Dumas	53.55	.....	5.48	29.22	....	5.74	6.01	.....
Clichy........	Dumas	45.60	.....	6.10	28.10	....	6.20	14.00	.....
Bohemian... Champagne.	Maumeno	58.40	9.90	1.80	18.60	....	8.90	2.10	.....
Champagne...	Maumeno	62.21	5.69	1.91	22.93	....	6.10	1.16	.....
German.......	Benrath	69.82	18.28	1.50	7.82	....	2.58	2.58	.....
German.......	Benrath	62.78	19.14	11.24	6.11	....	0.73	0.73	.....
Russian.......	Benrath	65.77	11.75	11.75	16.58	...	5.90	5.90	.....
Russian.......	Benrath	68.38	19.03	19.03	10.19	....	2.40	2.40	.....

The above tables of glass analyses were taken from Elements of Glass and Glass Making by Benjamin F. Bizer.

PROPERTIES OF GLASS.

Glass possesses peculiar chemical and physical characteristics, the combination of which isolate it from other substances. Among these are transparency, viscosity, elasticity, devitrification, specific gravity, expansion and contraction, tensile and crushing strength, non-conductivity, decay, and iridescence.

Transparency.—Colorless glass is pervious to light and has the property of transmitting all the rays of white light without appreciable absorption. The degree of transparency in glass depends, first, upon the proportion of the raw materials and the thoroughness with which they are mixed in the preparation of the batch. Unless the batch contains the proper proportion of raw materials to form a chemical compound in the fusion, a homogeneous transparent mass of glass cannot be formed. And, second, the transparency depends upon the completeness of the fusion of the batch in the melt. Insufficient heating prevents a proper fusion, and repeated heating tends to crystallize the glass and largely destroys its transparency by causing it to become tough, fibrous, hard, and causing a multitude of grains, chords, and semi-opaque matter, disseminated throughout the glass.

Viscostiy.—One of the most important properties of glass is its power, in the viscous state, to yield continually under stress. After the batch is melted and the major portion of the impurities has been driven off through evolution and expulsion of the generated gases, the glass is in a liquid condition. In this condition it cannot be worked but as the heat is diminished, or, as it is chilled by exposure to air, it becomes viscous. In this viscous state it is ductile and tenacious and capable of assuming any shape. It can be rolled like dough with an iron roller and can be formed into hollow shapes by the pressure of the human breath or by compressed air. So extensible is viscous glass that it can be drawn out into a filament sufficiently fine and elastic to be woven into a fabric. Therefore, it is during the viscous stage that glass is best adapted to the principal processes of manufacture. On further cooling the glass rapidly assumes a solid condition and soon becomes hard and brittle.

Elasticity.—The elasticity of glass is such that, when in a viscous condition, it may be spun into minute threads, which when cold, may be bent, twisted or woven into cloth. A ball of glass let fall upon an anvil will rebound two-thirds the distance of its fall. This elasticity is due to a play of the particles in the glass ball which return to their original position when the disturbing force is removed.

Devitrification. Devitrification is the conversion of amorphous, transparent glass into a crystalline, opaque material by very slow cooling. Ordinary glass is cooled suddenly and therefore lacks crystalline structure. But glass that is repeatedly heated and cooled in the process of manufacture devitrifies and has a tendency to become tough, difficult to fuse, and fibrous; and usually many solid grains of semi-opaque matter are disseminated through it. Devitrification may be prevented by a careful regulation of the length and number of times the glass is heated and the temperature to which it is heated.

Opacity and semi-opacity which always occur in devitrified glass may be produced by adding to the batch materials such as oxide of tin, oxide of arsenic, or phosphate of lime, which will remain in suspension in the glass. The change in the structure in the glass consists simply in the formation of so-called crystallites, or small srystals in the glassy bases. Those glasses with bases containing lime, alumina, and magnesia in excess devitrify easiest. Glass, such as window, that is subjected continually to the action of the

atmosphere and gases, devitrifies, i. e., becomes dull and opaque and looses its lustre and transparency.

Specific gravity. In the manufacture of glass little attention is paid to specific gravity except in the manufacture of object glasses, lenses, artificial gems, and similar articles. The value of these depend upon their power of refracting light and, since the light-refracting power of glass increases with the increase of molecular weight, the specific gravity of glass varies with its composition. This ranges from 2.5 in the lime glass to 5.0 in the heavy lead glass. The specific gravity of glass is also slightly influenced by the amount of contraction resulting from cooling. It is further influenced to a slight extent by the relative amount of the volatile matter driven off. The specific gravity increases with the expulsion of volatile matter.

Expansion and contraction. Glass is affected by changes in temperature and follows the rule of expanding when heated and contracting when cooled. The amounts of expansion and contraction for equal changes in temperature are not equal in all grades of glass, but are higher in glasses containing the alkalies, especially soda and potash. The decadent effects of expansion and contraction caused by daily changes in the temperature of the atmosphere will be discussed below. Great and sudden changes in temperature may cause sufficient expansion or contraction to break the glass. Hot water poured into a thick glass bottle or jar often breaks the vessel. This is because of the expansion produced on the inner surface while the outer surface is still cool. If the changes in temperature can be made to take place uniformly throughout the mass there is little danger of breaking, but as glass is a poor conductor of heat this condition is seldom realized except in very thin glass.

In the manufacture of glass care should be taken to produce as nearly as possible an absolutely uniform homogeneous body, in order to guard against the effects of contraction and expansion. This is accomplished by annealing. The process of annealing is discussed later.

Tensile and crushing strength. The term tensile strength as here used refers to the amount of force necessary to break a glass rod or bar of given cross-section by straight pull. Crushing strength refers to the weight necessary to crush a glass body of given dimensions usually a cube. The tensile strength of glass is greater than that of granite and ranges from 6,000 to 10,000 pounds per

square inch. The tensile and crushing strength of a glass depend much upon the manner in which it is annealed.

A glass well annealed has less structural lamination, or flakiness, and less undue internal tension than a glass improperly cooled; because the molecules are allowed time to effect a greater degree of compactness and the pores thus become regularly and uniformly closed or at least diminished in size throughout the entire body which, by this process, acquires regular and dependable strength. The effect of improper annealing is illustrated by putting a piece of hot glass in cold water. The sudden cooling causes rapid and unequal contraction in the molecules of the glass near the point of contact and fracture occurs.

Non-conductivity.—Glass is a poor conductor of heat, but one of its peculiar properties, generally speaking, is that it transmits the luminous heat rays and absorbs the non-luminous. This is evidenced by the fact that a person may stand by a window on which the sun is shining and feel the warmth of the sun, yet if he touches the window it will feel cold. On the other hand, the same piece of glass when placed between him and a fire will shield him from the heat, but in so doing becomes rapidly heated itself. If the claim of different glass experts, however, can be substantiated, a window glass which will not transmit heat rays may soon be in common usage. This grade of glass is supposed to absorb a large per cent of the heat striking it and thus keep a house cool in summer and tend to keep it warm in winter.

Decay.—Many think of glass as a hard substance, devoid of crystalline structure, impervious to both liquid and gaseous fluids, and capable of preserving its beauty, retaining its surface, and not even losing any of its substance by the most frequent usage. It is, however, subject to decay, and is attacked by almost all substances which come in contact with it. A characteristic indication of decay is a dullness of color with a gradual increase of opacity, decomposition finally setting in just as in rocks and minerals subject to weathering.

The chemical composition of glass determines, to a large extent, the rate of decay. Its resistance to decay increases with rate of approach to, and decreases with departure from a definite chemical compound, and its constituents dissolve in about the same ratio as they are contained in the glass. The larger the amount of alkali in any glass, the more easily the glass is attacked by the simultaneous action of the moisture and carbonic acid when exposed to atmos-

pheric moisture. The change in color is due to the combined action of the carbonic acid and atmospheric moisture which form an insoluble crystalline film of silica upon the surface of the glass as a result of the action upon the silicates. The carbonic acid and atmospheric moisture also form a soluble silicate with a base which decomposes and leaves the surface pitted. This offers greater surface for additional moisture and consequent forces to aid in its destruction. Hydrofluoric acid attacks glass readily by decomposing the silicates, and forming fluorides with silica and its metallic bases. Hydrochloric, nitric, sulphuric, and phosphoric acids, and even pure water by prolonged action exert a decomposing influence.

Iridescence.—As has been stated, glass in the process of decay becomes pitted and laminated, that is, composed of thin plates or scales. In glass of this kind a beautiful iridescence or rainbow-like play of interference colors of much brilliancy is frequently observed. This play of colors is due to the thin films of air between the minute scales of glass and to the irregular surface of the pits, both of which refract and decompose the rays of light. Iridescence is produced in glass by artificial means with a fair amount of success. The best methods adopted are those which alternate the refractory power of the external layers of the glass by subjecting them to vapor from volcanic ashes or to the combined action of heat, pressure, and weak acids. Many beautiful effects may be produced in this way.

RAW MATERIALS.

Sand.

As previously noted, the chief constituent of glass is silica in the form of ordinary sand. In the preparation of the batch, however, chemically prepared basal and auxiliary substances are added. Soda, potash, lime, and lead constitute the principal basal elements used, and nitre, salt-cake, arsenic, antimony, and manganese the principal auxiliary elements. The kind and amount of material added in each case is controlled by the hardness, luster, color, or other properties desired. The several ingredients will be discussed in the section treating of basal and auxiliary substances. Only a small per cent of the accessory ingredients comes from the alkalies and other substances which are added to the sand to form the batch. It follows, therefore, that the color, transparency, brilliancy, and hardness

of the glass are determined largely by the quality of the sand which is the only one of the components occurring in a natural state, the others being chemically prepared substances.

The factors which determine the value of a deposit of sand for glassmaking are : (1) chemical composition; (2) physical properties; (3) available supply; (4) conditions of quarrying, or mining; and, (5) location with respect to fuel supply, transportation facilities, and market. These will be discussed in order.

Chemical Composition.

Silica.— Sand is composed principally of silica (SiO_2), and the purest glass sands contain practically 100 per cent of this oxide, with only traces of impurities. From this maximum all gradations in composition may be found down to sands containing such large percentages of impurities that they cease to be sands. The best grades of glass sand obtained from the Illinois and Missouri fields are reported to contain from 99 to 99.9 per cent silica, while the poorest grades sometimes run as low as 90 per cent silica.

Impurities.—The most harmful impurities found in sand are iron, clay, magnesia, and organic compounds. Iron is a strong colorizing agent imparting to the glass a green, yellow, or red color, which varies with the amount and the degree of oxidation of the iron. Aluminous substances (principally clay) lessen the transparency of the glass and for the higher grades their presence in excessive amounts must be avoided. The presence of magnesia raises the fusion point of the batch and thus more fuel must be used to melt the charge. Organic matter is a strong colorizing agent and produces a dark amber color.

To neutralize the colorizing effects of these impurities upon glass, decolorizing agents are sometimes used. The principal decolorizing agents are manganese, arsenic, antimony, potassium nitrate, nickel oxide, and cobalt oxide. These ingredients are used in small quantities, since in large quantities they become colorizers instead of decolorizers.

The percentage of impurities allowable in glass sand depends upon the grade and character of glass desired. For the finest flint ware, such as optical and cut glass, only the purest sand can be utilized, perfect transparency, great brilliancy, and uniform density of product being required.

For manufacture of this ware the sand should not carry more than .05 per cent of iron (ferric oxide, Fe_2O_3), or .1 per cent of alumina (Al_2O_3). For the manufacture of plate and window glass, however, which are commonly a pale green, and which do not require as pure a grade of sand, .2 per cent each of iron and alumina is not injurious; and, in some cases, as when decolorizing agents are used, the sand usually contains .3 to .4 per cent iron and .6 to .7 per cent alumina. Some grades of English plate and window glass contain as much as 1.92 per cent iron and 2.68 per cent alumina. The French mechanically pressed plate glass averages about .14 per cent iron and 1.27 per cent alumina, and the English, .49 per cent iron and .7 per cent alumina. Lead glass contains as high as 1.93 per cent each of iron and alumina, and lime glass, as high as 5 per cent iron and 6.22 per cent alumina. In the better grades of bottle glass the iron averages about .65 per cent and alumina about 2.2 per cent. Since sand forms only 50 to 80 per cent of the batch, the percentage of iron and alumina may be still higher than these figures.

Methods of Chemical Analysis.

The writer finds no great amount of information extant on methods of chemical analyses of glass sand. In the present investigations two methods were used, the results of each being checked against those of the other in every analysis. The first, or direct method is that ordinarily employed in silica analysis and will be disucussed first; the second, or hydrofluoric method, will then be treated briefly, wherein will be shown the manner in which results were made to check against those obtained by the first method.

The Direct Method.

Preparation of sample.—In order to hasten the fusion and the total decomposition of the ingredients of the sand it was found necessary to grind it into a fine powder. As a means of securing an average sample in each case several hundred grams of the sand were taken and well mixed. From this about four grams were taken, placed in an agate mortar and ground to a fine powder.

Fusion with silica flux.—One gram of the finely pulverized sample was mixed thoroughly with five grams of a silicate flux which was composed of 53 parts by weight of sodium carbonate (Na_2CO_3), and 70 parts by weight of

potassium carbonate (K_2CO_3). The mixture was placed in a covered platinum crucible and by means of a Bunsen burner was heated until all was in a state of quiet fusion. At this point the crucible was placed over a blast lamp and heated to a white heat until no bubbles were seen to escape.

When the fusion was complete the crucible with the contained fused mass was immersed in cold water to about one-half the height of the crucible. The immersion caused the fused mass to cool suddenly and shrink away from the crucible thus loosening itself and making removal easy.

Determination of silica.—The fused mass was then transferred from the platinum crucible into a 400 c. c. casserole and about 100 c. c. of hot water were added. In order to remove all of the fused mass from the platinum crucible, about 10 c.c. of dilute hydrochloric acid (HCl) were added to the crucible and gently heated on the water bath for a few minutes. The dissolved contents were then washed into a small beaker with a jet of hot water and the operation repeated until all the fused mass was dissolved. The casserole was covered with a glass and the solution from the small beaker was carefully transferred to it, care being taken that nothing was lost by effervescence. The contents of the beaker were then transferred to the casserole, and to the contents of the latter about c.c. of concentrated hydrochloric acid were added. The casserole was then placed on a water bath and heated until all the fused mass was dissolved. Sometimes small amounts of the silica were left in the bottom of the crucible and flocculent particles were seen floating about in the solution. In such case the solution was filtered and silica subjected to a second fusion and the contents added to the casserole. The casserole was then placed on a water bath and the solution evaporated to dryness; 25 c.c. more of concentrated hydrochloric acid were added and the solution evaporated to dryness again. The solid substance was removed from the bath and ground thoroughly in a mortar and again transferred to a casserole. The casserole was again covered with a watch glass and this time placed in a drying oven heated to about 135° C. and let remain forty-five minutes. About 50 c.c. of dilute hydrochloric acid were added and the casserole placed on the water bath and heated until all the contents except the silica were dissolved. While being heated the solution was stirred with an ordinary glass rod. The solution was filtered through an ashless filter paper into a 200 c.c. graduated flask and thoroughly washed with hot water, the washings

being caught in a beaker. The wet paper and silica were placed in a weighed platinum crucible and heated over a Bunsen burner until the paper was charred. The temperature was then raised and the crucible kept red until the silica became white. The crucible was cooled in a dessicator and weighed. The weight of the silica multiplied by 100 gave the percentage of the silica.

The filtrate from the silica contained the alumina (Al_2O_3), lime (CaO), and magnesia (MgO). The contents of the beaker were evaporated to small bulk and washed into a 200 c.c. graduated flask. The solution was cooled and the beaker then filled with pure water to the mark. A stopper was inserted and the solution was well mixed by shaking. With a graduated pipette, 100 c.c. of the solution were removed into a 250 c.c. beaker and the pipette and first beaker were washed into their respective beakers.

Determination of iron (Fe_2O_3) *and alumina* (Al_2O_3).—To each beaker a drop of nitric acid (HNO_3) and about 5 grams of ammonium chloride (NH_4Cl) were added and the solution heated to boiling, after which the solution was removed and, when cool, sufficient ammonia was added to give a decided odor. The solution was boiled again for a few minutes and then set aside for the precipitates to settle. After settling the precipitates were filtered out through separate 11 cm. ashless filter papers and washed thoroughly with hot water until the last drops produced no trubidity with silver nitrate ($AgNO_3$).

To one of the filter papers just mentioned 25 c.c. of dilute (1 in 5) c. p. sulphuric acid (H_2SO_4) were added and the dissolved precipitate was received in a 100 c.c. Erlenmeyer flask. The filter paper was washed three or four times with hot water.

In order to reduce the iron from the ferric to the ferrous condition, a piece of platinum foil was placed in the solution in contact with a piece of c. p. stick zinc and allowed to remain one hour. The solution was then filtered into a beaker and the filter washed.

The solution and washings were placed under a burette and titrated with a weak standard potassium permanganate ($KMnO_4$) solution. One c.c. of the permanganate solution equaled .0014 grams of iron. The number of c.c. and tenths used, multiplied by .0014 gave the weight of the iron; this was multiplied by 2 because the previous solution was divided into two parts. The weight of iron multiplied by 100 gave the percentage of iron.

The other filter paper and contents were placed in a weighed platinum crucible and heated over the Bunsen burner until the paper was charred. The crucible was then heated to a white heat over a blast lamp for five minutes. It was then cooled in a dessicator and weighed. The increase in the weight of the platinum crucible gave the weight of the alumina and iron. The weight of iron as found in the manner above described was subtracted from the total weight and the result multiplied by 200 gave the per cent of alumina.

Determination of lime (CaO).—The filtrates in the two 200 c.c. beakers above mentioned together with the washings from the alumina and iron precipitates were transferred into a larger beaker and the 200 c.c. beakers washed into it. Five grams of ammonium chloride and sufficient concentrated ammonia (NH_4OH) to give a decided odor were added. The solution was heated to boiling and, while boiling, 25 c.c. of a hot solution of ammonium oxalate [$(NH_4)_2C_2O_4$] reagent strength were added. The boiling was continued until the silght precipitate granulated. The solution was set aside to allow the precipitate to settle, then filtered and placed in a weighed platinum crucible. Ignition was begun over the Bunsen burner, and finished over the blast lamp. The increase in the weight of the platinum crucible divided by 2 and multiplied by 100 gave the per cent of lime.

Determination of magnesia (MgO.)—To the filtrate and washings from the calcium oxalate precipitate in the operation above described nitric acid was added and the solution concentrated by boiling to about 100 c.c. The solution being cooled, 5 c.c. of ammonia and 25 c.c. sodium ammonium phosphate ($HNaNH_4PO_4$) were added and the solution was set aside in a cool place for 24 hours. It was then filtered and washed twice with small portions of two per cent ammonia. The precipitate was placed in a weighed platinum crucible and treated in the same manner as the calcium oxide. The magnesium phosphate ($Mg_2P_2O_7$) thus found, multiplied by the factor .3624, and this result by 100, gave the percentage of magnesia.

Determination of organic matter.—Two methods were used in the determination of organic matter. In the analyses of the sands containing a small amount of limestone, the following method was used:

Five grams of the sand (not pulverized) were placed

in a weighed platinum crucible and ignited for a half hour over the Bunsen burner, and then five minutes over the blast lamp. The crucible and contents were cooled in a dessicator and weighed. The loss of weight gave the amount of organic matter, as all the samples analyzed had been exposed long enough to lose all but atmospheric moisture. In the analyses of the sands containing limestone in any considerable quantity the following method was used: About five grams of the sand were placed on a weighed filter paper and washed with dilute hydrochloric acid until all of the limestone was decomposed into calcium chloride ($CaCl_2$) and calcium oxide (CaO). These were washed through the filter paper by repeatedly pouring small amounts of warm water on the contents of the filter. The filter and contents were then dried in a drying oven for one hour at a temperature of 100° C. and cooled in a dessicator, after which they were weighed. The total weight less the weight of the filter paper gave the weight of the silica and other non-volatile substances plus the weight of the organic matter. The procedure from this point on was the same as the method above.

No quantitative analyses were made for titanium, sodium or potassium, because qualitative tests on the sands showed that they do not occur in sufficient quantities to be harmful.

Hydrofluoric Acid Method.

As above mentioned, in chemical analyses the writer employed the foregoing or direct method, and the hydrofluoric acid or indirect method, checking the results of each method against those of the other. The procedure in the latter method consisted briefly as follows:

Two grams of the finely pulverized sand were placed in a platinum dish and about 7 c. c. hydrofluoric acid (HF) were added drop by drop, the mixture being stirred at the same time with a platinum wire. A few drops of sulphuric acid were added and the mixture was evaporated to dryness on a sand bath, and then heated over the naked flame of a Bunsen burner until all fumes ceased coming off. It was found necessary to repeat this process about twice before all the sand was decomposed by the hydrofluoric acid. After the silica was expelled by the repeated evaporations in hydrofluoric acid and sulphuric acid, the mass was digested with hydrochloric acid until all went into solution. The silica was obtained by the difference. The other con-

stituents were determined in the filtrate by the same methods as in the previous method.

Physical Properties.

Shape of grains.—The prevailing opinion among glass sand experts has been that the sand grains should be sharp and angular, never rounded and smooth. The contention has been that the rounded and smooth grains do not leave as many interstices through which the heat can pass as do the sharp angular grains. For this reason it has been maintained that the round grains have a tendency to settle to the bottom of the batch in the melting pot and prevent an even flux, producing an unevenness and irregular quality in the glass. Some of our prominent glass men of today, however, are of the opinion that more attention has been given to the shape of the grain than is warranted, and they contend that it is not an important factor and that any good silica sand, if of a proper degree of fineness. will become liquified very readily. This conclusion has been reached because of the fact that several prominent glass plants in the Mississippi Valley are successfully making both the ordinary grades of glass and the fine flint wares from the sand composed entirely of rounded grains.

The Oklahoma sands are prevailingly subangular. Most of the grains show irregular fracture surfaces, angles and edges. In the case of those grains larger than the 60 mesh the angles and edges are more or less rounded; while of the grains smaller than 80 mesh there are almost none that are not sharply angular. The general rule is the smaller the grain the more angular it is.

Size of grains.—There are also varied opinions as to the most desirable size of the grains. There are those who contend that the size and shape of the grains have nothing to do with the quality of the glass, but that a small grain will melt more quickly and consequently require less fuel, as the flux can act only on the surface of the grain. But the prevailing sentiment is that to produce the best results the grain should not be larger than 30 mesh nor smaller than 120 mesh. If the sand is pure, however, the size of the grains may have a somewhat wider range and still good results be obtained, so long as the grains are comparatively uniform in size.

The finer sand is said by some to "burn out" in the batch and not produce as much glass per unit as does coarser sand. The grains larger than 30 mesh on the other

hand are more difficult to fuse. This lowers the amount of sand each furnace can melt per day and consequently increases cost of production. As already noted, in a mixture of coarse and fine sand the finer is liable to settle to the bottom of the batch, thus preventing an even mixture of the materials and producing in consequence a glass uneven in texture.

Physical Tests.

Determination of the size of grains.—In the present investigation in order to determine the size of grains, a series of sieves of 40, 60, 80, 100, and 200 mesh were arranged in regular order, the coarsest above and a pan beneath the series. One hundred grams of sand were placed in the 40 mesh and covered with a tight lid. The nest of sieves was then taken in the hand and given one hundred circular motions. The sand was removed from each sieve and weighed, the amount retained on each gave directly the per cent of sand that was unable to pass that particular mesh. Although in the coarser screens there is a larger percentage of mesh space in proportion to the total area than in the finer sieves, owing to the fact that in the coarser sieves the diameter of the wire is less proportionately to the size of the mesh than in the finer sieves, the ratio of volume of material to mesh spaces is approximately preserved. On the whole, therefore, it seems that the best results were obtained by shaking all the sieves together.

Available Supply.

There are numerous small deposits of good glass sand near fuel and accessible to transportation facilities that can never be developed in the United States, because the deposits do not contain a sufficient quantity of sand. Glass sand is not very valuable. In 1910 its average price in the United States was $1.04 per ton. It is obvious that at this price, the sand must occur in sufficient quantities and under such conditions as to reduce operating expenses to a minimum. Under favorable geographic and geologic conditions thin ledges affording relatively small amounts of sand may be worked at a profit while the cost of working thicker ledges unfavorably situated would be prohibitive. Ordinarily a deposit of sand 20 feet thick should have an areal extent of 25 acres of good sand in sight to warrant the erection of a mill and construction of trackage.

Conditions of Quarrying or Mining.

Character of sand.—The ease with which sand may be removed from the ledge and prepared for mixing depends largely on the degree of its consolidation or induration. Other things being equal, a loose friable sand which may be worked with a steam shovel or by similar means is preferable to an indurated sand which must be blasted in order to remove it from the quarry, as well as ground to prepare it for mixing into the batch. Some sands were once firmly cemented or perfectly indurated but have become friable through the solvent work of waters slowly precolating through them.

Character of outcrop.—In a general way the sand occurring in a bluff is more easily worked and is usually obtained at less expense than that secured by removing the surface soil and working from above. Sharp contacts with rocks above and beneath are to be preferred because usually under this condition a less amount of the sand is likely to be contaminated with foreign material from the other rocks.

Drainage.—Glass sand is often more easily eroded than the rocks with which it is associated and as a result is often found outcropping in ravines and creek beds. Especially is this true of the sands in Oklahoma. In selecting a place to open a quarry care should be taken to avoid a location in which surface waters might interefere with quarrying.

Location.—Good transportation facilities and a ready market are indispensable to a glass sand industry. The locality that is handicapped by poor transportation facilities or an unsteady market cannot hope to be a successful competitor. Since fuel is so important a factor in the manufacture of glass it is also evident that a sand must be within reasonable distance of a center of fuel supply, the glass factories being necessarily located at some such center.

Basal Substances.

Soda, potash, lime, and lead constitute the major basal substances of all commercial glass. They are necessary as reducing and combining agents with the silica in the formation of the silicate glass. In addition to these, salt-cake, nitre, borax, saltpetre, and barium carbonate are quite often used and may be classed as minor basal substances.

The table already given in the section on the classifi-

cation of glass shows approximately the extent of variation of amount of these basal substances.

The several major basal substances will be briefly discussed in order:

Major Basal Substances.

Soda—(soda-ash, sodium carbonate, Na_2CO_3) constitutes the principal base for most of the commercial glass of the present day. The chief source of soda to supply the demand of the earliest glass houses was obtained from the natron lakes of Egypt. In later times the soda was obtained from the ashes of certain plants that grew in the sea or along the seashore. The natron secured by these two methods was very impure and produced a glass inferior in every way.

Realizing the need of a purer grade of soda, the French Government offered a reward of 12,000 francs to any one who would succeed in devising an artificial process of converting common salt (NaCl) into soda. Nicholas LeBlanc succeeded in accomplishing this in 1790 and this discovery opened up a new era in the glassmaking industry. The LeBlanc process was universally used until 1863, when Earnest Solvay devised the ammonia process. This latter process has replaced the LeBlanc process since it is simpler and more effective. Solvay's process consists in treating a pure solution of salt charged with ammonia with pure carbonic acid. The precipitates of sodium carbonate formed is purified by filtering, drying, and heating.

Soda is crystallized sodium carbonate deprived of its water of crystallization. Its value depends upon the sodium oxide (Na_2O) which forms practically 58 per cent of the mass. During fusion 31.67 per cent of the soda is lost through evaporation and volatilization. In addition to its acting as a reducing and combining agent with the silica, as has already been mentioned, the soda-ash adds a brilliant lustre to glass.

As already noted several compounds which may be called minor basal substances merit separate discussion. They are:

Potash (pearl-ash, potassium carbonate, K_2CO_3).—Potash produces fusion in the batch more readily than soda, and also produces less coloring; but since it diminishes the brilliancy of the glass and is somewhat more expensive than soda, it is not used to any great extent in the manufacture of glass.

Lime (calcium oxide, CaO, and calcium carbonate, $CaCO_3$).—Lime in the form of calcium oxide or calcium carbonate is a very important ingredient in glassmaking. It is an alkaline base, facilitates fusion, adds stability, and increases the insolubility of the glass. Care must be taken that the proper amount be added, since an excess retards fusion, hardens the glass, and renders it more liable to devitrification, and also produces a milky appearance in the glass. The amount of lime required varies considerably in the different glasses, the limits being as follows: window glass, 8 to 15 per cent; plate glass, 3.5 to 16 per cent; bottle glass, 6 to 30 per cent; lime flint, 5 to 16 per cent.

Litharge (PbO) and *red lead* (Pb_2O_3).—Litharge and red lead, once extensively used in glass manufacture, have been largely replaced by soda. They are used now only in the manufacture of artificial gems, optical glasses, and similar products possessing as they do the power to produce brilliancy and density. Red lead is preferred to litharge because of its being in a finer state of subdivision and because it liberates oxygen readily upon fusion. This ready liberation of oxygen facilitates the removal of the impurities.

Lead glass is very soft, highly refractive, and dense, and is less apt to break when exposed to sudden changes in temperature.

Minor Basal Substances.

Salt-cake (sodium sulphate, Na_2SO_4).—Salt-cake is made by decomposing sodium chloride (common salt) with sulphuric acid. The sulphate is known as Glauber's salt. It contains ten molecules of water of crystallization, or 55.9 per cent of its weight. Although this water of crystallization is driven off before the salt is used, yet 56.3 per cent of the remainder is lost during the melt.

Salt-cake is sometimes used instead of soda because it is cheaper and renders the glass less liable to devitrification and produces a harder glass which will take a better polish and be less liable to sweat. In recent years, however, salt-cake, for the reasons given below, has largely given way to soda. It requires 130 to 150 pounds of salt-cake to produce the same quantity of glass as 100 pounds of soda. The salt-cake usually contains more iron and other impurities than the soda and also produces fumes that are destructive to the pots, tanks, and walls of the furnace. Because of these impurities, the glass made from the salt-cake is

more deeply colored. The prevailing color is a bluish green which is chiefly due to the presence of iron. The most serious objection to the use of salt-cake in the batch is the fact that 10 to 20 per cent more fuel is required than if the carbonate were used. The additional amount of fuel is necessary because a higher temperature is required to force the silicic acid to decompose the salt-cake than is required to decompose the soda. To aid in this decomposition carbon is added to the batch, generally in the proportion of one equivalent of the carbon to two of the salt-cake. The carbon added abstracts one oxygen equivalent from the sulphuric acid leaving sulphurous acid which readily forms a silicate of sodium and hence aids in fusion. Care must be taken to get the carbon thoroughly disseminated throughout the batch, otherwise quantities of undecomposed sulphate may occur in the glass. In a few places vegetable and animal fats, oils, and similar substances are successfully substituted for carbon.

Nitre (Chili saltpetre, sodium nitrate, $NaNO_3$).—Sodium nitrate enters the batch in conjunction with the other alkaline bases and acts as an auxiliary base. It is used chiefly as an oxidizing and decolorizing agent, since its oxidizing properties aid in the expulsion of the carbonaceous matter, thereby facilitating the fusion and improving the quality and color of the glass.

Borax (sodium borate, $Na_2B_4O_7+10H_2O$).—Borax is a powerful flux and facilitates the fusion of the batch, by its readily becoming a fluid at a comparatively low temperature. At the fusion point it bcomes considerably agitated and this agitation has a tendency to purify the glass by dispersing and expelling many of the impurities in the batch.

Saltpetre (potassium nitrate, KNO_3).—Potassium nitrate is very seldom used in the manufacture of glass and then only as an oxidizing agent in the finer wares.

Barium carbonate ($BaCO_3$).—Barium carbonate is sometimes used as a substitute for lead, lime, potash, or soda: but, since it is more costly and less pure than the other bases, it is not generally used. Pure barium carbonate facilitates fusion, imparts lustre, adds hardness, and increases the density of glass.

Auxiliary substances.

The auxiliary substances used in the manufacture of

glass are cullet, manganese, arsenic, antimony, cobalt, zaffre, nickel, and bone-ash. These are added to act as deoxidizing and decolorizing agents to remove or neutralize the accidental color which is usually produced in the glass by the impurities contained in the raw materials. They are often added also to impart special colors to the glass, but this phase of the subject will be treated later under the heading of "Colored Glass."

Cullet.—Cullet is pulverized waste glass. When added to a batch it should be as near the nature of the glass desired as possible, otherwise the product will have a tendency to become stratified and lumpy. Cullet is more fusible than the raw materials in the batch and, therefore, when properly disseminated throughout, it facilitates fusion since it keeps the materials open and in a porous condition. This facilitates also the transmission of heat through the mass. When the transmission of heat is well regulated undue loss of the alkalines through volatilization is prevented and also a more uniform product is obtained. The cullet should not be used in excess of possibly one part of cullet to two parts of sand, since in larger quantities it reduces the strength, firmness, elasticity, and resistence of the glass and causes it to become very brittle.

Manganese.—The manganese used in glass manufacture is chiefly the dioxide (MnO_2). It is a strong oxidizing and decolorizing agent and is often termed "the great decolorizer of glass." The chief function is to neutralize the greenish color imparted to glass by the protoxide of iron (FeO). From every 100 parts of the dioxide 18½ parts of oxygen are set free. This liberated oxygen combines with the protoxide of iron to form the peroxide (Fe_2O_3), which produces a reddish-yellow tint in the glass and neutralizes the green tint produced by the protoxide. This oxygen set free by the managnese also assists very materially in washing out the impurities from the constituents and thus aids in purifying the color of the glass. The use of manganese, however, is being largely abandoned in the manufacture of glass that is exposed to the continued action of sunlight, especially window glass, since the sunlight produces chemical changes which render inconstant the color in glass containing manganese.

Arsenic (As_2O_3).—The function of arsenic in the manufacture of glass is that of a purifier. It acts principally upon the carbonaceous matter present and is often called

"the great decarbonizer of glass." In addition to the removal of the impurities from the constituents and their expulsion, by means of carbon dioxide formed, the arsenic in small quantities also facilitates the fusion and decomposition of the other materials. Color imparted by arsenic is not affected to any noticeable extent by continued exposure to sunlight. Hence arsenic is used extensively as a decolorizer in window glass. Care must be taken, however, to avoid using an excessive amount of arsenic since it produces an objectionable milky color in the glass, which increases with age.

Antimony (Sb_2O_3).—Antimony is very seldom used in glass manufacture, and then only as a substitute for arsenic. In small quantities it performs the same function as arsenic. facilitating fusion and aiding in the elimination of impurities. In excessive quantities it produces objectionable effects and is even more deleterious in its effects than is arsenic.

Cobalt, zaffre, and nickel are sometimes used in the manufacture of lime and other flint glasses as decolorizing or neutralizing agents. *Bone-ash*, [calcium phosphate, usually $Ca_3(PO_4)_2$], is also sometimes added in small quantities to the batch, especially of opal glass, as a decolorizer, since it is especially active in neutralizing the impurities.

Before leaving this phase of the subject it will be in order to note that the basal and auxiliary substances are manufactured products and hence are not important factors. as are sand and fuel, in the location of a glass plant.

FUELS.

Experience has shown that the success of the glass industry in a given locality is determined largely by the fuel supply. The fuels are wood, coke, coal, oil, natural and producer gas. In the early days the fuel consisted in *wood* thoroughly dried or baked. In the last 50 years it has given way to other fuels. In recent years *coke* also has been superseded, therefore, both of these many elimated from the discussion. Recently, in many localities in the east the industry suffered for lack of cheap fuel and in many places plants have suspended operations. On the contrary the industry in the Mississippi Valley has made a wonderful progress. In Kansas and Oklahoma the rapid progress is due to the large amount of cheap fuel furnished by the Mid-Continent natural gas fields, while in the other states it is

due to the large supply of bituminous coal which is used in the manufacture of producer gas. As an example of the value of cheap fuel to the glass industry it may be noted that there are about 25 glass plants in southeast Kansas and six in northeast Oklahoma, obtaining their sands from east Missouri and yet successfully competing with the plants located in the sand regions of Illinois, Missouri, and Indiana. This is because the plants in Kansas and Oklahoma have a large supply of natural gas which they obtain at four cents per thousand cubic feet, while the plants located in Missouri, Illinois, and Indiana are paying eight to twelve cents per thousand cubic feet for producer gas.

Coal probably takes precedence over all other fuels for glassmaking. This is true because it is found in almost inexhaustable quantities near most of the large glass sand deposits in the United States. Used directly it is not the best fuel since the smoke and by-products have always been a serious objection, especially where the materials to be melted are exposed to direct action of the flame. But in this country very little coal is used directly as a fuel in the manufacture of glass, but vast quantities are consumed for producer gas. When coal is utilized in this manner the chief objections are overcome. There seems to be an increasing preference for producer over natural gas, because the supply is constant.

Oil is not used to any great extent as a fuel in the glass industry as it produces no better results than other fuels and is much more expensive. To operate successfully with oil a more or less complicated system of burners for generating gases or producing combustion in some other manner is required. This entails too great an expense to make the use of oil profitable.

Natural gas, where found in sufficient quantity, is the ideal fuel. It produces a constant and intense heat and no harmful by-products are given off. In a great many of the eastern districts, however, the supply is fast diminishing and is so uncertain as to cause the manufacturer much annoyance and loss.

Producer gas. In most of these localities the manufacturers are substituting producer gas for natural gas. This is generated from bituminous coal by a process of destructive distillation and is beyond question the best form of fuel yet utilized in the glass industry, as the heat produced is intense and its use gives a direct saving in fuel of from 35 to 70 per cent.

The gas producers are usually arranged outside the glass works where all the manipulations of feeding, of stoking, and of removing the ashes are performed without interfering with the work inside. Care must be taken to place the gas producer at a lower level than the furnace in the glass plant as the gas has a natural tendency to pass upward to the furnace.

FURNACES, POTS, AND TANKS.

The outer walls and the pillars of furnaces are constructed of ordinary yellow or red brick, or of common building stones. The wall lining and all parts exposed to intense heat are constructed of high grade fire brick. Little mortar is used and that is made of a refractory clay and pure sand.

The clay best adapted for the manufacture of fire brick for glass furnaces should be as pure as possible and very refractory, breaking with a clear, smooth, bright fracture, and free from lime and calcium sulphate and should contain the least possible amount of iron. The most essential property in good fire clays, or in any of the objects made from them, is a high fusion point. To obtain this high fusion point the clay should be free from metallic oxides, such as lime and iron, which unite with the silica with comparative ease. In addition to being refractory the clay must also be sufficiently plastic to be readily moulded and at the same time should not shrink much.

Before the final decision can be given on the adaptability of a clay. an examination of its physical properties must be made, its plasticity, bonding power, amount of water required to make a plastic mass, specific gravity, tensile strength, shrinkage in drying and in burning, vitrification, viscosity, slaking, fineness of grain, feel and color, and the proper proportion of other ingredients required in mixing must be determined. A fire clay used in the manufacture of glass pots or high grade fire bricks should have a formula approximating closely to $Al_2O_3 2SiO_2 2H_2O$.

The fire brick should be even and rather open in texture, fairly coarse in grain, and free from cracks or warping. Since there are no single fire clays which will produce brick that meet all these requirements it is customary to make the fire brick from a mixture of a plastic fire clay, a non-plastic or flint fire clay and ground fire brick or other form of burnt clay. The clays are seasoned, ground, thoroughly kneaded or pugged, and then mixed with the

ground fire brick or grog. Fire brick are usually molded in hand molds, repressed on hand represses, dried on steam-heated floors, and burned in down draft kilns at high temperatures.

In order to protect the surface of the fire brick from the disintegrating effects of the flue gases and other deteriorating substances, the surface of the brick is washed with a thin paste of some very refractory material such as kaolin. Very recently a thin paste of carborundum and clay, or carborundum and silicate of soda has been used for the same purpose. These materials melt and run over the surface and form a glaze, which prevents deposits of clay on the sides of the furnace, pot or tank by retarding corrosion.

Glass pots and tanks are made from a very high grade fire clay or mixture of clays. The clay is weathered, ground, tempered by pugging or treading, and then allowed to season for a considerable length of time in order to develop its maximum plasticity and working properties. The pots or tanks are usually built by the hand of skilled labor. Several are started at the same time and a few inches built on to each one each day until the whole set is finished. The size of the pots or tanks for different kinds of glass may vary considerably. The walls are usually about 4 inches thick. The drying of the large pieces must be done very slowly and requires several weeks. Before being used the pots are tempered by being heated gradually to the temperature required in their use in the furnace and then cooled slowly. When in use the pots are fired once each day until they fail by breaking or loss of material by fluxing. There is great variation in the life of pots, some break on their first firing while others may last for fifty or more firings. The average is probably about twenty casts per pot.

A great many of the clays for the construction of furnace pots and tanks are imported into this country from Germany, but there are large deposits of excellent clays for this purpose in many localities in our own land. The chief supply, however, is obtained from Missouri, Pennsylvania, and New Jersey. The Missouri plastic clays are purer than the German clays and have a fusing point ranging from 2400° to 2800° F. They are more refractory than the German clays but not as dense and do not resist the action of the fluxes so well. So far no suitable fire clay for glass furnaces, pots, and tanks have been found in this state.

Silica is used in furnace, pot, and tank building in the form of a slightly plastic siliceous sand or in the form of a

loose disintegrated sandstone which is crushed between rollers, mixed with about one per cent of lime and molded into bricks and heated in kilns at a very high temperature. These bricks, because of their heat-resisting power, are used for the roof, fire arches, flues, and other parts subjected to intense heat.

Alumina chiefly in the form of bauxite is used as a refractory material, but its applications are somewhat restricted. It has been found that under long continued heating the alumina changes into a substance as hard and refractory as natural emery.

Coke dust or graphite is largely used in an admixture with fire clay in the production of pots and tanks. The proportion of the coke dust or graphite added to the clay varies with the quality from 25 to 50 per cent. The articles made from this admixture are the most enduring of all.

Glass furnaces are constructed according to many different patterns with varying degrees of complexity in arrangement, yet modern glass furnaces may be divided into two general classes, namely: pot furnaces, and tank furnaces. The pot furnaces are usually constructed in the shape of a square or oblong for the manufacture of flint glass. Tank furnaces are arranged to give either continuous or intermittent results without the use of pots and may be of almost any shape, but are usually oblong. Tank furnaces are now more commonly used than pot furnaces and are gradually replacing them. This change is due to the increased production, economy in working, economy in time, durability of furnace, regularity of working, and superority of the glass produced by the tank furnace over that of the pot furnace.

A few of the furnaces are built to consume coal or coke by its direct introduction into the furnace. But as already noted, coal or coke, on account of smoke and by-products, is not often used by direct firing for the better grades of glass and in the last few years almost all of the furnaces have been equipped for natural gas or producer gas.

The ordinary furnace heated by coal or coke is composed of three essential parts, namely: the fire place, in which the fuel is consumed; the melting chamber, in which the tanks or pots are placed; and the apparatus for producing rapid combustion by the supply of air to the fire. The fuel is placed on a grate which occupies the center

of the furnace. The combustion gases then pass into the melting chamber where the pots or tanks are placed.

Pot furnaces have no fixed size, neither is the number nor size of the pot themselves fixed. In the manufacture of plate glass the pots are filled with the mixed raw material and then placed in the furnaces by means of long tongs mounted on wheels, and are removed in the same manner after the firing. For blown ware, such as bottles and lamp chimneys, the pots or tanks are stationary in the furnace and the material is introduced through a small arched opening situated directly over each pot, except in the case of the covered pot in the furnace for making flint glass, in which case the mouth of the pot extends outside the furnace walls. After the mixture is properly fused, the molten glass may be withdrawn from the pots or tanks through openings in the furnace walls by means of long rods which are dipped into the molten mass.

The gas furnaces consist of two principal parts, namely: a combustion chamber and a producer. The combustion chamber is essentially the same in the gas furnace as in the coal or coke furnace. In the latter class of furnaces the hot gases from the combustion chamber are usually allowed to escape into the air through flues, but in the more modern plants much of the energy contained in these gases is utilized by means of the Sieman's system of regenerative heating. It is the most perfect method of utilizing the waste heat that has been tried. Its value lies in the fact that the spent gases are made to travel through chambers, known as regenerators, which contain a large number of thin fire bricks arranged with narrow interspaces so as to offer a very large heat-absorbing surface. These thin fire bricks absorb much of the heat from the spent gases and soon become red hot. Then the current is diverted to an adjacent chamber and the acquired heat in the fire bricks is removed by a current of cool gas and air passing toward the furnace, where it arrives sufficiently heated to insure the greatest possible heating effect. As soon as the chamber is cooled the action is reversed and the gas and air pass through the chamber which has just been heated, while the waste gases reheat the first chamber or chambers and prepare them for again performing their functions.

Some electric furnaces have been erected for melting and molding quartz. Their success would seem to suggest the possibility of electricity being employed in the future for the manufacture of glass.

Mechanical Processes.

The raw materials, fuel, furnace, pots, and tanks have been discussed and now we come to the manufacture of glass itself. There are three stages in the manufacture of glass, namely: first, the synthesis of the materials; second, molding; and third, annealing.

The Synthesis of the Materials.

By the synthesis of the materials is meant the entire process from the assembling of the raw materials, through the successive steps till the batch is completely melted. This synthesis is accomplished by mechanical and by chemical processes.

Mechanical Processes.

Compounding of the batch.—In the preparation of the batch only the experienced glass makers who possess a sufficient amount of technical and practical knowledge to make a careful and accurate calculation of the quantity of ingredients necessary for the grade of glass desired, should be employed. Although the batches vary greatly in the different grades of glass and although even in the same grades of glass different glassmakers use the materials in widely varying proportions, yet glass is a chemical compound and the same grade under similar conditions always requires the same amount of bases, fluxes, colorizers, or decolorizers and other accessories. The varying amount of materials used in the preparation of the batch by different glassmakers for the manufacture of a certain grade of glass, may be due to a difference in the arrangement, equipment, and serviceability of their furnaces or to a difference in fuel and to irregularity in raw materials; otherwise a slightly different grade of glass will always result. In other words, in order to insure a uniform result, it is necessary to make careful calculations and chemical tests of the raw materials. No guess work or uncleanliness should be tolerated, and all ingredients should be carefully weighed, ground, and sifted.

Silica is the foundation and chief constituent of all commercial glass but most of its special qualities are dependent upon the bases, fluxes, and colorizing or decolorizing agents. As an example, an increase in the quantity of bases, fluxes, etc., causes the glass to soften and to lose strength, resistance, tenacity, and lustre; while a decrease in the quantity of the ingredients increases the hardness,

strength, tenacity, and lustre, but also raises the fusion point.

It is important to remember that the quality of a glass improves or deteriorates as its composition deviates from that proportion required to form a definite chemical compound, and that the softness, hardness, durability, briliancy, uniformity, homogeneity, and color of a glass are largely dependent upon the proportion of the raw materials in the batch.

Mixing.—A thorough and uniform mixing of the raw materials in the batch is necessary in order that a proper chemical association may take place when the batch is melted, and homogeneity and uniformity in the structure of the glass be insured. The mixing should be done by a machine as it gives more accurate, thorough, and uniform results than can be obtained otherwise. To insure this proper mixing of the raw materials, the bases, fluxes, etc., should be finely pulverized and sifted thoroughly.

Chemical Process—The Melt.

Fusion.—After the materials in the batch have been added in the right proportion and thoroughly mixed mechanically, they are then transferred to the pot or the tank which has been previously heated to a sufficiently high temperature so that melting begins immediately. When fusion is accomplished a chemical compound is formed. This process completes the association.

Upon melting, the raw materials in the batch disintegrate, and moisture, acids, and gases are expelled. In this way the aggregate bulk is decreased and room is left in the vessels for additional material which is introduced about twelve hours after the first filling. One refilling is usually sufficient, although in some cases it is best to add several successive smaller amounts.

It is important that before filling, the vessel be heated above the fusion point of the batch and this temperature maintained. In this manner a homogeneously fused mass is obtained, the fusion proceeding regularly from the bottom upward and from the sides toward the center. The first filling should be completely melted before any more raw material is added, otherwise the liquefaction of the remainder and the escape of the gases and impurities will be retarded by the addition of the second filling.

During the fusion of the raw materials, chemical dissociation is continually taking place, gases and acids being formed. These gases and acids perform a double function, first, generating an agitation of the particles in the semi-fluid mass and thus aiding in the production of a homogeneous and even-tempered product; and second, absorbing, expelling, or otherwise disposing of most of the impurities of the batch in the process of fusion. If at any time the temperature of the batch falls below the fusion point and the dissolution and agitation cease, "glass goll" is likely to be produced. This is simply masses of non-fused particles of the batch remaining disseminated in suspension throughout the melted material. The "glass goll" impairs clearness and transparency by producing white blotches and spots in the glass. Another serious result of insufficient and irregular heating is that the volatile ingredients of the batch escape at a temperature which is not sufficiently high to fuse the silica. Another deleterious effect is that the alkaline silicates fuse more easily than silica, resulting in a partially crystalline structure in the mass. This devitrification manifests itself in the form of stones, cords, and striae.

Refining.—Refining consists in removing, or other wise freeing the fluid mass of, its many seeds, bubbles, and other impurities which are found in the batch just after it is melted. This purification is accomplished by increasing the temperature to about 3400° F. At this temeprature the mass becomes very fluid and the infinitesimal seeds, bubbles, and other impurities either escape through volatilization or gather on the surface where they may be removed by skimming. As soon as the glass is purged of these impurities the temperature is decreased gradually and the mass reduced to a viscous state. While the mass is cooling it is usually stirred with a fireclay cylinder which is inserted through a small opening at the upper end of the containing vessel. The object of this operation is to render the glass as homogeneous as possible by freeing it of veins, cords, and striae. The cylinder is allowed to remain in the viscous mass only for a short time when it is exchanged for another since its surface quickly oxidizes resulting in scales which contaminate the glass. The stirring is continued until the glass has cooled to such degree of consistency that the cylinder can hardly be moved, when it is discontinued and the cylinder removed. From this point on no molecular movements occur and the glass remains a homogeneous mass.

Molding.

According to the methods used in manufacture, all glass products are divided into the following classes: optical glass, blown glass, and pressed glass.

Optical Glass.

Optical glass is the most expensive glass made and demands the greatest skill, precision, and care in its manufacture, since a good quality requires perfect transparency and freedom from colors, homogeneity, great hardness, absolute chemical stability, absence of internal strain, and high power of refraction and dispersion. To secure the qualities only raw materials of the purest grades may be used.

In the process of molding and annealing optical glass the desired amount is taken, and heated to a temperature just sufficient to soften the glass. It is then placed in a mold made of iron or fire clay and forced to assume the shape of the mold. The glass which is now in the approximate form desired is placed in a heated chamber and passed through the process of annealing. The minimum time allowed for annealing optical glass is six days, while for "fine annealing" several weeks are sometimes consumed.

Oftentimes at the end of the fine annealing process as much as 1,000 pounds are found in one single mass which is free from cracks and fractures and is entirely intact; but it is usually found broken up into a number of pieces of various sizes. The larger pieces are used for lenses and mirrors of considerable dimensions such as are required in telescopes of large aperture. The smaller pieces are utilized for the production of discs and slabs with which the general optical glass trade is usually supplied.

The discs or slabs at the end of the annealing process are slightly larger than the size required by the opticians and therefore must be ground down. Sometimes defections cannot be detected until grinding is complete or nearly so, hence rigid inspection is required before the finished discs and slabs are delivered to the trade.

Blown Glass.

Blown glass embraces, first, table ware and vases; second, tubes; third, sheet glass; and, fourth, bottles and similar articles.

Tableware and vases.—The tools used in the production of tableware and vases are simple and extremely primitive.

They consist of lathes; hollow, iron blowing rods; spring tools with steel or wooden blades to fashion the viscous glass; callipers and measuring sticks; molds of carbon, cast-iron, gun metal, wood, or plaster of Paris; and strong rods for holding the vessels during manipulation.

The method of making a tumbler illustrates all the ordinary processes used in the manufacture of tableware and vases. A sufficient amount of viscous glass to form the tumbler is gathered on the end of a blowing iron, and rolled on a polished slab or iron, called the "marvor," to solidify it. The solidified mass is then fashioned by being blown into a mold. In case a vessel with a foot (such as a goblet) is desired the mass is blown into a particular mold which gives the desired shape to the bowl and also forms a leg. A small lump of molten glass is added to the extremity of the leg and by being trundled and pressed between slabs or against an upright board the foot is fashioned. The bowl of the tumbler is then severed from the blowing iron and put in an annealing oven. When the tumbler is cold it is removed from the oven and the rough fractured surfaces are polished by grinding or smoothed in a gas flame. Sometimes the surplus glass is removed by some such method as applying heat to a line that has been scratched by a diamond.

Tubes.—Tubes are made by blowing a hollow mass of viscous glass. They are used chiefly in thermometers, test tubes, and similar laboratory and other articles. Viscous glass has the peculiar property of retaining its shape while being drawn out. As an example, if a triangular thermometer tube is desired the molten mass is pressed into a V-shaped mold. On being drawn out the V-shape is retained.

Sheet glass.— Numerous inventions have been made recently in an endeavor to procure a direct method by more or less mechanical means that can be substituted for the complicated and indirect process that is in vogue at present in the manufacture of sheet glass. None of these have proven entirely satisfactory, however, because of the difficulty of transferring the molten glass to the machines without the introduction of air bells which are always formed when molten glass is poured from one vessel into another. The complicated and indirect process described below is typical of the methods in use in the majority of the sheet glass works.

Sheet glass is generally fused in regenerative tank furnaces, some of which have a capacity for as much as 250 tons of molten glass. These furnaces are tilted and have a temperature gradient, the upper end being hotter and the lower cooler. There is a continuous movement of the liquid material from the hotter upper end to the lower cooler end where the glass is in a viscous condition. The glass is withdrawn from the lower end of the furnace through openings provided with movable covers, by means of a ladle or gatherer's pipe. This pipe is an instrument composed of an iron tube about 5 feet in length with an enlarged butt at one end, and a wooden covering used as a handle and mouthpiece at the other. The gatherer dips the butt of his previously heated pipe into the molten glass and withdraws it. The small ball of viscous glass that adheres to the butt cools while the mass is being rotated in the air so as to keep it as nearly spherical as possible. As soon as the mass has cooled sufficiently, the whole is again dipped into the molten glass and another layer adheres. It is again withdrawn and the process repeated until the proper amount of molten glass has been gathered to yield the sheet which is to be blown.

The gathering is then placed in a block or mold and rolled and blown until it acquires roughly the shape of a hemisphere, the diameter of which is approximately that of the cylinder which is formed in the next step.

The hemispherical mass is now taken over by the blower and introduced into some special furnace or "blowing hole". The blower, by swinging and blowing, extends the mass into the form of a long cylinder which is closed at the lower end. In small thin cylinders the closed end is spun out to the diameter of the whole by the centrifugal effect produced by rapidly spinning the pipe between the hands, while with large thick cylinders the opening is accomplished by an assistant attaching a small lump of viscous glass to the closed end, which softens the glass of the cylinder sufficiently to enable him to cut the end open with a pair of shears, and the opening is then accomplished as in the case of the small cylinders.

The pipe is next detached from the cylinder by applying cold and hot irons to the neck of the hot glass that connects the pipe-bath and cylinder. The cylinder is then prepared for the flattening furnace first by cutting the rough ends with a diamond applied internally, and second splitting it longitudally by the same means. In the flattening fur-

nace the split cylinder is exposed to a sufficiently high temperature to soften the glass and is then placed upon a smooth flat slab and flattened by a rubbing instrument composed of a block of charred wood or some similar material. The sheet of glass finished, only the process of annealing remains. This is accomplished by the methods discussed under the head of Annealing.

Bottles.—More progress has been made in the last decade in the manufacture of bottles than in any other grade of glass, and the demand has increased to such an extent that the manufacture of bottles has become an industry of vast proportions.

In recent years bottle-making machines have been successfully operated and they are destined to replace the old method of manufacturing in which most of the manipulation in the process is done by manual labor, because the machines insure absolute regularity in form of the vessel and save both time and labor. Since both methods are used at present a brief description of each will be given.

Five persons are required by the old process of bottle manufacture. The gatherer gathers the glass from the tank furnace on the butt of a blowing iron, rolls it on a stone or iron plate and, after slightly expanding the glass by blowing, hands it over to the "blower", who places the glass in a mold, closes the mold with a lever, and by means of compressed air or the breath, forces the glass to take the form of the mold. The bottle is removed from the blowing iron by applying a moistened piece of iron to the neck of the bottle and tapping it. The bottle is then gripped with a clip and handed to the "bottle maker". The bottle maker attaches a piece of molten glass to the end of the fractured neck and with a specially arranged tool simultaneously shapes the inside and outside of the neck. The "taker in" then removes the bottle to an annealing furnace, where it is properly annealed by being placed on trucks which are moved slowly away from a constant source of heat in a heated furnace so adjusted as to cool slowly.

The different bottle making machines vary considerable in details, yet the general principles involved are the same. The machine patented by Michael Owens contains a revolving table carrying five or six molds which are opened and closed by cams operated by compressed air. The blowing iron with the molten glass attached to it, which has just been gathered from the furnace, is placed in a mold. It is soon

in contact with an air jet which admits compressed air and forces the glass to assume the form of the mold. The bottle is then removed from the machine, severed from the blowing iron, and the rough edges smoothed. The annealing is accomplished as above noted. In some other makes of bottle machines, the molten glass is placed in a funnel-shapped vessel, and a plunger is thrust upwards into the glass from beneath, forcing a part of the glass into a mold stationed above which forms the neck. The funnel is removed and the plunger, neck mold, and molten glass attached to the neck are inverted. A bottle mold then rises and envelopes the molten glass, immediately after which compressed air is admitted to an opening in the plunger and forces the molten glass to take the form of a bottle mold. After annealing the bottle is ready for the market.

Mechanically Pressed Glass.

With a few minor exceptions all products of this class are pressed by mechanical means, and comprise chiefly plate glass.

Plate glass.—When the molten glass has cooled to a viscous condition, the whole pot with its contents is transported by means of huge tongs or cranes operated by mechanical means, to a rolling table, and the viscous mass poured on the casting table which usually consists of a perfectly smooth cast-iron slab mounted on a low massive truck running on rails so that it can be readily moved to any desired position in the casting room. As soon as the viscous mass is poured on the table a large roller, sometimes weighing as much as five tons, is passed over the glass, pressing it into a sheet, the width of which is regulated by guides pushed along in front of the roller, while the thickness is regulated by raising or lowering the roller relatively to the surface of the table. Figured rolled plate is produced in this way also by using rollers which have the pattern imprinted upon them.

Since the surfaces of the glass produced by rolling are uneven and must be ground and polished, it is essential that care be exercised in the handling and annealing of the large sheets, otherwise irregular thickness would be formed and extra expense incurred in grinding away the extra mass. The annealing process is therefore carried out in specially arranged annealing kilns, composed of large fire brick chambers containing sufficient floor area to accomodate several large slabs. The chambers are low and the slabs are placed

on blocks of burnt fire clay which form the floor of the kiln. In order to prevent any displacement and to give sufficient room for expansion, the blocks are set slightly apart resting on a bed of sand. After the kiln has been sufficiently heated and the glass introduced, the opening through which the glass is introduced is built up with fire brick and fire clay and the whole is then allowed to cool. Air passages or special cooling channels are provided in the walls and floor of the kiln, and by a gradual opening of these to admit the air the colling is greatly accelerated and the larger slabs may be satisfactorily annealed in three or four days. The slabs are then transferred from the annealing kiln to the cutting room where they are cut into the different desired sizes and shapes.

The glass is now ready to receive its final form. It is placed on a rotating table, and either two surfaces of glass, or, one surface of glass and one cast iron, are rubbed together with the interposition of sand, emery, carborundum, or some other powerful abrasive. The surface is soon ground down to a plane and the pits produced are removed by grinding successively with abrasives of gradually increasing fineness, leaving ultimately a smooth gray surface. This smooth surface is then brilliantly polished by adding some polishing material, such as rouge, and rubbing with an instrument covered with some soft material like leather or felt.

Annealing.

Annealing is the gradual cooling of heated glass sufficiently slowly to allow the constituent particles to settle into a condition of equilibrium. In spite of the fact that annealing is one of the principal processes in the manufacture of glass it is the least understood, and manufacturers seem content to use the primitive methods that have been handed down from generation to generation. There are two methods of annealing in vogue at present, one being to move the glass gradually away from a constant source of heat by means of a train of small iron trucks drawn along a tramway by an endles chain, and the other, to allow the heated kiln to die out gradually. The latter method is used especially in annealing large quantities of glass at a time.

Glass follows the general law of expanding when heated and contracting when cooled. If this cooling is brought about gradually the various stages of viscosity, ductility, and solidity are produced and the glass acquires regular and re-

liable strength, since the molecules are given time to rearrange and reset themselves from the center outward and so avoid molecular strain. On the other hand, if the glass is cooled rapidly the molecules on the cooled surface rush to adjust themselves and as a result the glass becomes intensely solidified, which prevents the molecules of the interior from uniting and reducing the internal porosity by adhesion to the solidified exterior. In this condition the glass is in a continual strain and is prevented from collapsing only by the intense rigidity of the exterior walls. At the least provocation, however, the surface will break and disintegration quickly ensues.

Colored Glass.

Historical.—Coloring glass is principal one of the arts of glass making and dates back almost as far as glass making itself. The principal colored vessels that are found in Egypt consist of small, columnar, stibian jars, flattened bottles, and tiny wide-mouthed vases and jugs, decorated with zigzag lines.

The earliest decorated glass consisted of patch work of little pieces of variously colored glass set together in a heavy fretwork of stone or imbedded in plaster. In the medieval period they were set together by strips of lead arranged something like the leter H. The character of the glass is explained by the fact that colored glass originally was not made on a large scale and in big sheets such as are produced nowadays, but rather in imitative jewels that were made to appear as much as possible like sapphire, ruby, emerald, and other precious stones.

The process of staining glass was at first primarily the art of the glazier, but the painter later on took almost complete charge of it and during the Renaissance developed it to such an extent that it was one of the most important and remunerative trades of that age. The greatest patron of glass painting was the church, and the art depended upon church building for its developement.

The last stage in the developement of glass painting was the employment of enamel to produce color. It was first used in the early part of the 16th century. Many colors were introduced but enamel has not proven successful and has fallen into disuse because the colors produced are not permanent.

Glass painting and the other medieval means of glass decoration have given way largely to more advanced and

systematic methods of coloring glass through coloring agents incorporated directly with the batch. White light is composed of an innumerable number of light waves of different lengths. The prism separates the component parts of white light into the seven prismatic colors, namely: violet, indigo, blue, green, yellow, orange, and red. Physicists have proven that color is caused by the vibrations of light waves, and that the different colors are due to waves of the different wave lengths. The rays of shortest wave length impart the sensation of violet; the next length, indigo; the next, blue; the next, green; and so on. The vision is not affected by those wave lengths that exceed that of the red. Again, if the various wave lengths reach the eye at the same time the result is the sensation of white light.

Light and color.—The seven prismatic colors are divided into three primary colors, blue, yellow, and red; and four secondary colors, violet, indigo, green, and orange. The primary colors are pure and cannot be produced by mixing other colors. Their color may vary in intensity but it cannot vary in hue. On the other hand the secondary colors may vary in hue indefinitely, by varying the amount of the primary colors from which they are formed. Again, two colors are said to be complementary to each other when by their mixture they produce white.

The color in glass is due to a chemical combination of the oxides of certain metals used as coloring agents with the silica, soda, lime, and other ingredients in the glass. The resultant product possesses the power to retard or extinguish certain of the components of white light and transmit the remainder. Some metals, such as iron, nickel, cobalt, manganese, and chromium form two or more series of compounds which produce different colors in a borax bead when subjected to the reducing and oxidizing flames of a blowpipe. As an example: Iron in the oxidizing flame gives a deep orange color, while in the reducing flame it gives a dull green color. Thus by varying the nature of the metal, quantity present, state of oxidation, conditions under which it is seen, and by blending different colors, hues, and intensity into new colors modified in tone and intensiy, an indefinite number of colors may be produced.

Coloring agents.—The principal coloring agents used in glass are manganese, cobalt, iron, gold, silver, copper, nickel, uranium, chromium, minium, antimony, selenium, zinc, carbon, calcium phosphate, sodium, selenite, tin oxide, guano, and borax.

Manganese when used in quantities in excess of those required as a decolorizer produces a color varying from rose to violet, purple, brown, and black, according to the quantity of manganese. When exposed continually to the action of the sunlight and air glass colored with manganese loses its color, since the manganese partly deoxidizes and becomes manganous oxide which produces no color in glass.

Cobalt is one of the principal coloring agents since it is cheap and produces positive results that are exceedingly easy to control. In small quantities it produces a deep rich blue color.

Iron in the ferric condition (Fe_2O_3) imparts an orange red color to glass; while the protoxide of iron (FeO) imparts a green color. *Gold* in the aurous condition produces a red color in glass. In fusing gold in the batch particular care should be taken to mix in the right amout of reducing agents so that the gold may not be super-oxidized to auric oxide; and on the other hand so that it may not be deoxidized to the metallic condition. Auric oxide does not color glass; while metallic gold produces a blue color which reflects a dull brown. Again, gold must not be added to any batch that will produce salt water or "glass goll", since it cannot be thoroughly disseminated in the batch so long as this impurity is present.

Silver is applied with a brush to the surface of the glass in the form of silver chloride mixed with some medium such as powdered clay, and heated gently in a muffle. The silver penetrates the glass and gives a light yellow to orange color. It is rarely introduced into the batch, because thereby it is reduced to the metallic state, and in this condition produces no color.

Copper forms two oxides, namely: the peroxide (Cu_2O) and the suboxide (Cu_2O) or red oxide. The former produces a green color and the latter a red or ruby color in glass. Reducing agents are added to the batch in order that the coloring agent may not be superoxidized. Care must be taken to avoid the use of ingredients that will generate "glass goll". Another important matter is the careful regulation of the temperature of the furnace and the thorough dissemination of the copper throughout the batch.

Nickel oxide produces a constant bluish to a violet tinge in glass. *Uranium* imparts a yellowish-green color, but is too expensive to be used except for the best grades of glass. *Chromium* oxide imparts an emerald-yellow which shades into a grass green. *Lead oxide* or minium yields a pale yel-

low color to glass. *Antimony sulphide* produces a yellow color. *Selenium* imparts a rose tint to glass. The depth and intensity of the color depends upon the quantity of selenium used and the quality of the glass. *Zinc* oxide produces a yellow color. *Carbon* which is generally added to the batch in the form of powdered charcoal, anthracite, or coke, produces a shade varying from straw color to dark amber. *Calcium* phosphate, or bone-ash, imparts an opalescent color in glass. The depth of the color depends upon the amount of lime used, and the temperature at which it is re-heated. *Tin oxide* produces a white opacity in glass, but since it is expensive, it is seldom used as a coloring agent. *Guano* imparts a white opacity in glass and is used instead of tin oxide, inasmuch as it is cheaper than the latter. *Borax* is sometimes used to intensify the color of glass.

CHAPTER II.

GLASS SAND DEPOSITS IN OKLAHOMA.

GENERAL REMARKS.

So far as is known the available glass sand deposits of Oklahoma occur in three regions, namely: the Arbuckle Mountains, southeastern Oklahoma, and near Tahlequah in northeastern Oklahoma. Beds of almost white sand, however, are reported near Tulsa, Bartlesville, Claremore, Ramona, Cleveland, Catoosa, Muskogee, and Holdenville, but so far as has been determined no large quantities of easily accessible sand in these regions has been found to be of sufficient purity to be used for anything but the poorest grades of glass, since all analyses show a large amount of iron oxide and other impurities which exclude them from consideration except for bottle glass. The deposits of each of the three principal areas will be considered in turn.

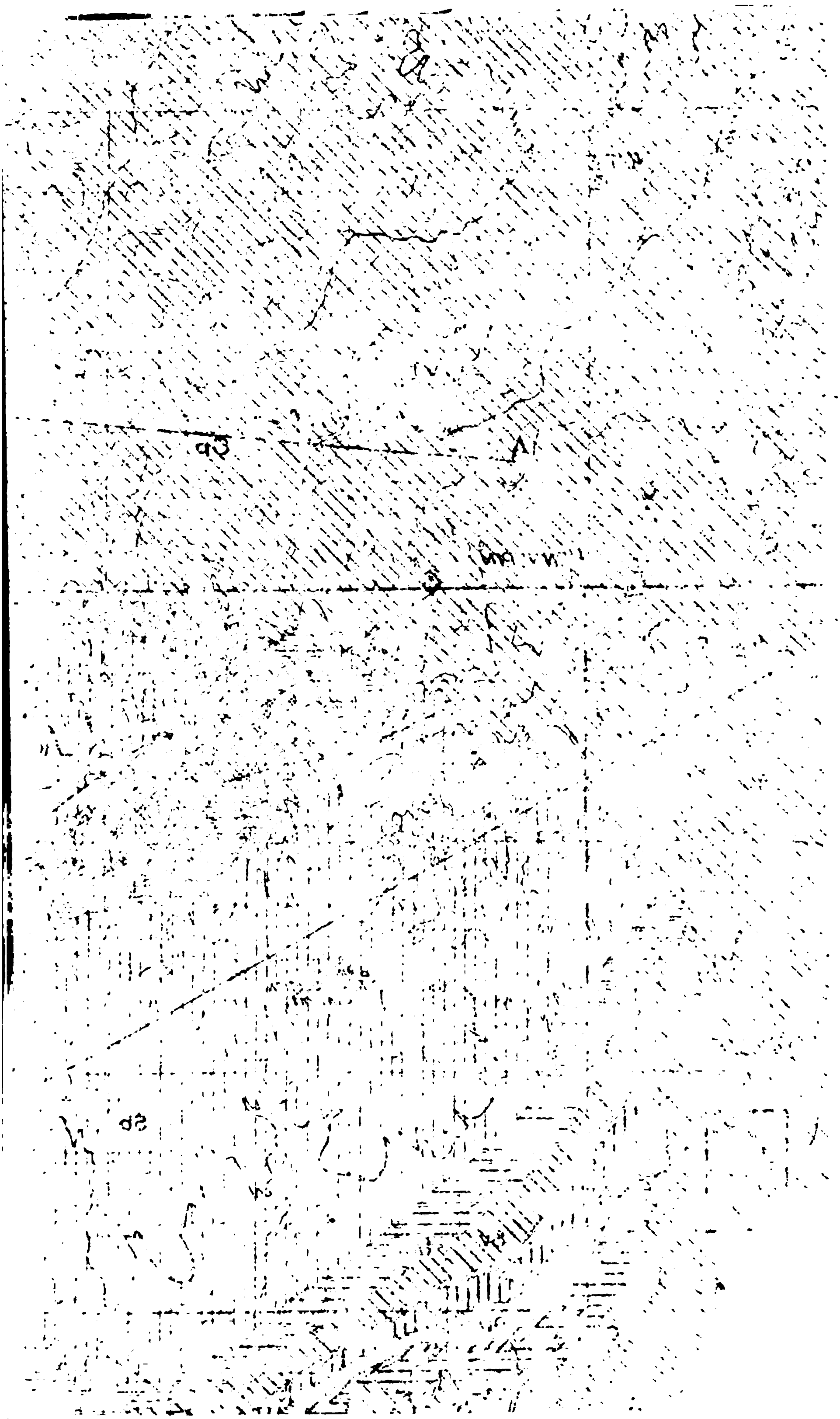
ARBUCKLE MOUNTAIN REGION.

General Features.

The Arbuckle Mountains consist of a low plateau, or table land situated in the southern part of Oklahoma, in Murray, Carter, Pontotoc, and Johnston counties. The Arbuckle Mountains proper form a roughly triangular area covering approximately 860 square miles. The plateau ranges in elevation from 1350 feet above the sea level in the western part to 750 feet in the eastern. On the northwest, the plateau is covered with Carboniferous conglomerate and "Red Beds" and on the southeast dips beneath the Cretaceous rocks. Plate I is a general geologic map of the region.

Mr. Joseph A. Taff[5] gives the following stratigraphic succession in the Arbuckle Mountains:

5. Geology of the Arbuckle and Wichita Mountains: Prof. Paper U. S. Geol. Survey No. 31, 1904; Tishomingo folio (No. 98), Geol. Atlas U. S., U. S. Geol. Survey, 1903.



Iron Prospects & Outcrops

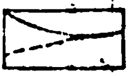
Zinc Prospects

Lead Prospects

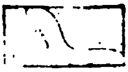
7.14

Surrendered
Indian Lands

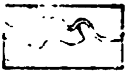
Geological Contacts



Fault Lines

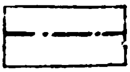


7.15 Contour Lines

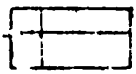


Rivers & Streams

Railroads



Quarter Lines



Township Lines

Age		Formation	Thickness in feet
Mississippian		Caney shale	1600
		Sycamore limestone	0-200
Devonian		Woodford chert	650
Upper Silurian		Hunton formation	0-300
		Sylvan shale	50-300
Ordovician		Viola limestone	500-750
		Simpson formation	200-2000
		Arbuckle limestone	4000-6000
Cambrian	Upper Cambrian		
	Middle Cambrian	Reagan sandstone	0-500

The chief topographic features of the Arbuckle untains are due to the varying resistance of the different mations, and to structure. The Sycamore, Hunton, Viola, Arbuckle limestones are hard rocks and resist erosion re effectively than the softer Caney shale, Woodford rt, Sylvan shale, and Simpson formation which are inter-ed between the harder rocks, alternating ridges and val-s resulting. Erosion has also been greatly influenced by arge anticlines and faulted synclines. Most the folding and faulting took place in Mississippian time er the deposition of the Caney shale.

The glass sand in the Arbuckle Mountains occurs in Simpson formation which outcrops as a belt around the buckle table-land. This table-land is formed by the Arbuck-limestone in Murray and Johnston counties and at other es in the mountains where the folding or faulting and sequent erosion have brought the formation to the sur-. The Simpson is composed of 1,200 to 2,000 feet of sand-ne and fossiliferous limestone with interbedded greenish

clay, shales, and marls. Taff[6] gives the following general section of the Simpson, taken on the south side of the uplift west of the Washita River, which with a few exceptions noted later, is characteristic of the Simpson throughout the area:

Section of Simpson formation on south side of Arbuckle uplift, west of Washita River.

		Feet.
1.	Thin limestone with green shales interstratified	400
	In the lower part the limestone is subcrystalline, resembling beds lower in the formation, while higher it becomes fine grained and argillaceous, resembling that of the succeeding Viola formation.	
2.	Sandstone	90
3.	Limestones and shales interbedded........	400
	Some of the limestones are highly fossiliferous: *Orthis tricenaria, O. deflecta, Monticuliporoid* Bryozoa, highly ornamented cystid plates, and species of *Ctenodonta*.	
4.	Sandstone	100-200
5.	Shaly limestone	195
	The lower 50 feet highly fossiliferous, containing Ostracoda with numerous Bryozoa and bases of crinoid columns, making a fauna sufficiently peculiar to be easily distinguished.	
6.	Sandstone	33
7.	Thin-bedded limestone and shales interstratified	295
	Contains fossils in great abundance, chiefly Ostracoda of large and small species, and numerous gasteropods, pelecypods, brachiopods, and trilobites.	
8.	Greenish shales with few thin limestone layers	245
	Thin sandstone.	
9.	Granular crystalline limestone in thin beds....	350
	Contains an abundance of Ostracoda (*Leperditia* chiefly) and other fossils so rare as to appear wanting.	
10.	Thin limestone and shales interstratified with occasional thin sandstone	29
11.	White to light-brown sandstone, occurring locally	0-100

6. Geology of the Arbuckle and Wichita Mountains: Prof. Paper U. S. Geol. Survey No. 31, 1904, p. 23.

On account of the large amount of shale and loosely cemented sandstone in the Simpson formation, it is much softer and more easily eroded than the Arbuckle and Viola limestones which outcrop on either side of it. Its outcrops, therefore, form belts of low land between the Arbuckle tableland and the rows of knobs of the Viola. with minor irregularities due to the varying hardness of the different members of the formation (fig. 1).

Fig. 1.

The Simpson is correlated with the Black River, Upper Stones River, and Chazy formations of Ordovician age. The beds of pure white sand in it are evidently beach or near shore deposits. Their purity, freedom from mud and other fine detritus, the comparatively uniform size of grains, and their sub-rounded character indicate long continued sorting action of the waters.

The workable glass sands in the Simpson occur within the limits of four well defined beds or series of beds, called in this report the basal, lower, middle, and upper beds. The basal beds contain sand only locally, but in some places the sand reaches a thickness of 200 feet, while the lower, middle and upper beds are fairly constant in thickness and character. The outcrops of these beds are usually marked with a heavier growth of timber than that found on the outcrops of the other members of the formation.

The Simpson formation is exposed in eight general areas in the Arbuckle Mountains, namely: the Southern Belt, which is a narrow strip along the south side of the mountains, the

Deleware Creek area, the Roff area, the Hickory area, the Mill Creek area, the Nebo area, the Buckhorn area, and the Davis area. In the following pages each area is discussed in some detail.

Southern Belt.

General Features.

The name Southern Belt is applied to the narrow strip of Simpson outcrop along the south side of the mountains, extending southeast from near Poolville to within three miles of Ravia, a distance of approximately 55 miles. The dip of the rocks in this belt varies from 18 to 80 degrees to the southwest, and the width of the outcrop varies from one-half to three-fourths of a mile.

The Sycamore limestone, Woodford chert, Hunton limestone, Sylvan shale, Viola limestone, and Simpson formation border the mountains on the southwest, all being steeply upturned. Because of their weaker resistances to erosion the Woodford chert, Sylvan shale, and Simpson formation form depressions which are usually wooded, alternating between the narrow limestone ridges. The Simpson formation is the thickest and most prominent, and outcrops in the wooded depressions between the row of rounded knobs of the Viola limestone on the south and a comparatively flat table-land of the Arbuckle limestone on the north. The Washita River and several smaller streams cut across all these formations almost at right angles, and form deep gulches or narrow canyons where they cross the more resistant formations. All the small streams, the more important of which are Henry House, Phillips, Cool, Oil, and Mill creeks, head in the more elevated parts of the Arbuckle plateau. Most of these streams contain water the year around. On account of the varying resisting powers of the beds of sandstone and shales in the Simpson, the formation is often etched by a number of small rivulets which parallel one another and empty into the larger streams that flow across the formation.

There is very little faulting in this area and the Simpson outcrop is continuous, except in the southwest corner of T. 2 S., R. 3 E., where it is faulted out. At the northwest end of the belt it passes beneath the Redbeds and in the southeast it disappears under the Cretaceous sediments.

At present none of this area is accessible to transportation facilities except that at Crusher, where the sand ledges outcropping along the bank of the Washita River are traversed by the Gulf, Colorado, and Santa Fe railroad. Condi-

tions are particularly favorable at this place since the sand, railroad, and water are in close proximity.

If at any time a railroad should be built along the level fertile plain at the base of the mountains on the south, unlimited supplies of pure white sand would be within easy reach, since the streams cutting their way across the formations have in most cases formed bottoms sufficiently wide to permit spurs to be built through to the sand ledges at little expense. The principal streams along which such spurs might be laid are Oil, Cool, Phillips, and Henry House creeks.

Occurrence and Character of Sands.

In order to obtain the thicknesses of the different beds in the belt several sections were made, the more important being on Phillips Creek, Cool Creek, at Crusher, on Oil, and on Mill creeks. These sections will be discussed severally.

Phillips Creek section.— The following partial section of the Simpson formation was made on Phillips Creek in sec. 25, T. 2 S., R. 1 E., the beds dipping west of south 52 degrees:

Partial section of Simpson formation on Phillips Creek (No. A1).

			Glass sand. Feet.	Total. Feet.
Upper Beds.	25.	Hard, brown sandstone containing much iron, and a few small seams of white, soft sand....		23
	24.	Shale		2
	23.	Hard, brownish, impure sandstone		10
	22.	Covered		16
	21.	Hard, white sand, good for bottles and the cheaper grades of glass	18	18
	20.	Green shale		252

Middle Beds.	19.	Impure sandstone		4
	18.	White, friable glass sand, good for bottles	4	4
	17.	Concealed, apparently sandstone		6
	16.	Beds of hard sandstone, 2 inches to 1 foot in thickness, alternating with softer beds...		14
	15.	Massive, soft white sandstone, good quality	8	8
	14.	Sandstone beds of unequal hardness and irregular in size of grain, containing too much iron for glass sand		12
	13.	Sandstone, limestone, and shale interstratified		16
	13a.	Massive, white sandstone of good quality	26	26
	12.	Coarse-grained, brownish-gray sandstone		10
	11.	Soft sandstone, good for bottle glass	8	8
	10.	Massive, white sandstone, good for all glassware except the best grade	12	12
	9.	Soft, irregular sandstone		11
	8.	Fairly massive, soft, white sandstone, good for bottles ...	8	8
	7.	Irregular beds of sandstone with considerable foreign material		28
	6.	Green shale with 4 thin ledges of coarse-grained sandstone ..		87
	5.	Hard, coarse-grained, siliceous limestone		8
	4.	Limestone and shale		330
Lower Beds.	3.	Thin layers of white sandstone varying from ¼ inch to 1 foot in thickness, interstratified with shale and limestone		12
	2.	Solid mass of white friable glass sand, good quality	12	12
	1.	Thin layers of white sandstone varying from ¼ inch to 1 foot in thickness, interstratified with shale and limestone		150

The sandstone in the above section is not sharply exposed and no fresh samples were collected as they could be obtained only with some difficulty. The sandstone was sufficiently exposed, however, to enable a fairly accurate determination of the quality of the sandstone in the different beds to be made.

Thin beds of good glass sand also occur locally at the base of the Simpson from Phillips Creek westward, but it is not in sufficient quantities to be worked.

Cool Creek section (No. A2).—Along Cool Creek, in sec. 35, T. 2 S., R. 2 E., a good exposure of the Simpson formation is offered, a partial section of which is as follows:

Partial section of Simpson formation on Cool Creek.

			Glass sand. Feet.	Total Feet.
Upper Beds.	9.	Not sharply exposed, surface indicates a solid mass of soft white unstratified sand. No appreciable quantity of impurities except in the 10 feet near the base	91	91
	8.	Limestone with interbedded beds of shale		461
Middle Beds.	7.	Impure sandstone		5
	6.	Massive, white glass sand......	53	53
	5.	Interstratified sandstone shale and limestone		25
	4.	Shale and limestone		200
Lower Beds	3.	Massive, white, friable glass sand	67	67
	2.	Brown, siliceous limestone		10
	1.	Sandstone grading rapidly downward into limestone		20

Certain units in the above section merit special and detailed consideration. Number 9 is practically one single bed of glass sand as nearly as can be determined. From this bed samples A1 to A6 inclusive were taken, analyses of which are shown in a succeeding paragraph under corresponding numbers. Sample A1 was taken 5 feet from the top; A2, 12 feet from the top; A3, 18 feet from the top; A4, 27 feet from the top; A5, 39 feet from the top; and A6, 60 feet from the top. These samples may be taken as indicative of the quality of the sand at the respective horizons. In the bed of the creek many little crevices are seen in the sand which would

seem to indicate the presence of thin layers of foreign matter. Higher up on the bank, however, where sand is not subjected so much to the action of running water the sand appears to be of one quality, showing that the crevices seen in the bed are due to unequal hardness of the sandstone caused by the varying amounts of lime which acts as a cementing material. The per cent of this lime as shown in the analyses is not large enough to make it unfit to be used as a glass sand.

Number 6 is also one solid mass of sandstone. From this bed samples A7 to A10 inclusive were taken. Analyses are given below. Sample A7 was taken 10 feet from the top; A8, 30 feet from the top; A9, 40 feet from the top; and A10, 50 feet from the top.

Analyses of samples of sand from section on Cool Creek.

No.	Fe_2O_3	Al_2O_3	CaO	MgO	SiO_2	Organic matter
A1	.07	.353	.138	.0137	99.305	.012
A2	.042	.661	.49	.0680	98.36	.011
A3	.042	.421	2.075	.0260	95.785	.013
A4	.028	.335	2.137	.0280	95.82	.0098
A5	.042	.421	.44	.1730	98.586	.0091
A6	.063	.48	8.81	.0540	83.787	.0063
A7	.084	.349	.463	.0170	98.706	.021
A8	.07	.213	.188	.0190	99.349	.029
A9	.084	.249	.028	.0260	99.585	.0018
A10	.133	.75	1.425	.0260	96.525	.0054
A11	.042	.216	3.146	.0790	94.07	.0014
A12	.028	.215	6.945	.0110	87.337	.001
A13	.084	.349	.463	.0170	98.706	.0027

Size of grains in samples of sand from section on Cool Creek.[3]

No. \ Mesh.	40	60	80	100	200	Pan.	Total
A1	.79	5.69	38.1	32.32	23.02	.1	100.02
A2	.86	5.5	45.64	29.57	18.39	.07	100.03
A3	.8	3.66	31.92	36.27	27.16	.2	100.01
A4	.71	2.34	40.5	36.72	19.48	.29	100 04
A5	1.59	8.52	51.64	26.37	11.81	.06	99.99
A6	1.05	2.27	39.43	35.31	21.83	.13	100.02
A7	2.93	9.98	31.42	26.97	28.44	.27	100.01
A8	1.72	4.2	17.62	34.04	42.09	.37	100.04
A9	1.3	3.46	21.97	33.62	39.56	.1	100.01
A10	7.68a	24.73	33.99	20.17	13.38	.04	99.99
A11	6.92	14.43	40.35	23.52	12.52	2.22	99.96
A12	28.23a	32.62	21.24	10.37	6.21	1.31	99.98
A13	6.17a	14.39	31.73	26.49	18.9	2.34a	100.03

a. Most of this can be mashed up finer between the fingers.

3. The per cent in each column of this and similar tables shows the amount of sand left on the sieve after 100 circular motions of the sieve in the hand, with the given number of meshes per inch.

Number 3 is one uninterrupted bed of glass sand from which sample A11, 20 feet from the top; A12, 43 feet from the top, and A13, near the botom may be taken as indicating the general quality of the sand. Analyses will be found in table. The beds of sand in the Cool Creek section dip 75° to the southwest.

Crusher section (No. A3).— One-half mile below Crusher on the Washita River is a good exposure of the Simpson. In the construction of the Gulf, Colorado, and Santa Fe railroad fresh exposures were made which greatly improved the natural section. The following succession was determined:

Partial section of Simpson formation at Crusher.

			Glass sand. Feet.	Total Feet.
Upper Beds.	17.	Siliceous limestone		7
	16.	Massively bedded white glass sand	36	36
	15.	Siliceous limestone		5
	14.	Alternating layers of shale and sandstone		45
	13.	Siliceous limestone		3
	12.	Brown impure sandstone containing much limestone		23
	11.	Fairly good grade of massive white glass sand but it is probably too thin to be worked.....	11	11
	10.	Coarse-grained sandstone with interbedded shale and limestone		56
	9.	White sandstone	11	11
	8.	Shales and limestone		387
Middle Beds.	7.	Siliceous limestone		7
	6.	Massive white sandstone	42	42
	5.	Siliceous limestone		5
	4.	Shale and limestone		526
Lower Beds.	3.	Massive white sandstone	86	86
	2.	Shale and limestone		202
	1.	Hard siliceous limestone		27

In the above section are several beds of valuable glass sand. The beds dip southwest at an angle of 75°. The character of the sand from No. 16 is indicated below in analyses of samples A14, taken from the top half of the bed, and A15 from the bottom half. Number 12 carries too

large percentage of lime to be considered a glass sand. The general quality of the sand from No. 11 is shown in analysis of sample A16. Number 9 has a small amount of high grade glass sand about the middle of the ledge, but the remainder is suitable only for the manufacture of bottles. Number 6 is not sharply exposed and no fresh samples were collected. The bed was sufficiently exposed, however, to enable one to determine fairly accurately its quality. The small amounts of sand gathered from different places in the ledge show that it is of as good a quality of glass sand as that found in the 53-foot ledge in the middle beds in the Cool Creek section which has already been discussed. Sample A17 shows the character of the sand in bed No. 3, 10 feet from the top. A18 represents the middle of the ledge while A19 was taken 10 feet from the bottom. The following table shows complete analyses:

Analyses of samples of sand from Crusher section.

No.	Fe_2O_3	Al_2O_3	CaO	MgO	SiO_2	Organic matter.
A14	.042	.161	.15	.03	99.469	.0013
A15	.042	.091	3.887	.031	92.941	.0032
A16	.07	.176	1.04	.054	97.844	.0097
A17	.028	.152	.37	.119	99.03	.008
A18	.14	.08	.2	.039	99.362	.005
A19	.056	.087	3.687	.042	93.236	.009

Size of grains of samples from Crusher section.

No. \ Mesh.	40	60	80	100	200	Pan.	Total.
A14	.67	2.45	31.12	36.00	27.69	.1	100.03
A15	6.74a	15.45	32.98	25.13	19.22	.04	99.98
A16	.80	1.10	32.18	34.46	28.39	.08	100.01
A17	.75	3.94	41.27	29.52	24.67	.06	100.01
A18	2.2	41.65	36.52	13.44	6.2	.02	100.08
A19	.54	42.54	36.85	14.25	5.84	.03	100.05

a. Most of this can be mashed up finer between the fingers.

The sand in this section is easily accessible. It outcrops on the bank of the Washita River in the large solid walls of the cuts of the Gulf, Colorado, and Santa Fe railroad. The strata are almost on edge and the river has cut across them approximately at right angles to the strike. The lower beds are represented by a single bed of 85 feet of good glass sand as shown in the analyses of samples A17, A18, and A19 above. The outcrop of the bed is 30 feet above the railroad at the edge of the cut and from this height the surface rises gradually for a distance of 560 feet back from the railroad to the top of the divide. At the top of the divide the outcrop turns gently to the south. The sand is more easily eroded than the associated shales and limestones of the Simpson formation and consequently the sand ledges usually outcrop in small ravines. On the north of the divide there is a small ravine which runs on the bed of sand to within 235 feet of the railroad. At this point the depression passes to the shales which lie below the sand and goes under the railroad 100 feet east of the outcrop of the sand bed.

The middle series is comprised in a single bed which is 43 feet thick and the whole is composed of glass sand. One hundred and twenty-five feet back from the railroad a small V-shaped ravine strikes the top of the bed and passes over the base of it at the point where it runs into a small culvert under the railroad. Each side of the ravine has a slope of about 30°. On account of this steep slope the bed, as it passes from the ravine to the side of the hill, is exposed only at short intervals, since it is covered with surface detritus that has worked down from above. The middle beds pass over the divide in the same manner as the lower beds.

The upper beds are 63 feet thick and are comprised of a single bed of good quality of glass sand as the analyses show. At the railroad cut the surface of the bed is 33 feet above the railroad and from this point it rises gradually to the southeast for about 1000 yards where it passes over the divide. On the divide it is about 100 feet above the railroad. Between the divide and the railroad the bed outcrops half way down the west slope of the hill.

Oil Creek section (No. 14).—On Oil Creek in sec. 17, T. 3 S., R. 4 E., is a good exposure of the Simpson formation. The beds here dip 82° to the south. A section of that part of the formation which contains glass sand follows:

Partial section of the Simpson formation on Oil Creek.

			Glass sand. Feet.	Total Feet.
Upper Beds.	19.	Sandstone, quality indeterminable	?	65
	18.	Shale and limestone		150
Middle Beds.	17.	Impure sandstone and limestone		40
	16.	White sand	15	15
	15.	Impure sandstone		15
	14.	Massive, white sand	45	45
	13.	Dirty, brown, shalv limestone.		9
	12.	White, hard sandstone	10	10
	11.	Siliceous limestone		22
	10.	Massive, white sand	45	45
	9.	Alternating sandstone and limestone		47
	8.	Shale and limestone		425
Lower Beds.	7.	Sandstone		25
	6.	Covered, very likely soft sandstone	?	20-50
	5.	Shale and limestone		663
Basal Beds.	4.	White glass sand	42	42
	3.	Impure sandstone		20
	2.	Massive, white sand	34	34
	1.	Coarse-grained, impure sandstone		5

In this section the basal sandstone 100 feet thick is found resting on the Arbuckle limestone. Seventy-six feet of this is a good grade of glass sand as shown by samples A20, A21, and A22. These basal beds are much more prominent than at Crusher, where they are composed of only a few feet of hard, siliceous limestone, while the middle beds are more than twice as thick. The upper and lower beds apparently contain approximately the same thickness of sand and as good a quality of sand as that found at Crusher, but they are not nearly so prominent and good samples could not easily be obtained from them. In the above section the quality of sand from No. 16 is shown in analysis A20 in the table below. Samples A21 and A22 indicate the quality of the sand from bed No. 14, the former being taken from the top 25 feet and the latter from the lower 20 feet. The character of the sand in bed No. 12 is shown in the analysis of sample A23. Sample A24 indicates the quality of the sand

in the upper 20 feet of bed No. 10, and A25, that of the lower 25 feet. Sample A26 shows bed No. 4 to be a very pure sand. Sample A27 was taken 5 feet from the top and A28, 2 feet from the top of bed No. 2.

Analyses of samples of sand from partial section on Oil Creek.

No.	Fe_2O_3	Al_2O_3	CaO	MgO	SiO_2	Organic matter.
A20	.07	.185	6.86	.0518	87.46	012
A21	.014	.179	.275	.021	99.267	.005
A22	.028	.255	2.075	.0771	95.94	.008
A23	.056	.277	5.925	.0645	88.947	.034
A24	.14	.383	11.225	.0699	79.357	.0098
A25	.056	.214	4.755	.0427	91.21	.0053
A26	.056	.284	.225	.0355	99.19	.0011
A27	.084	.146	.225	.0445	99.34	.0029
A28	.084	.162	.94	.028	98.058	.0084

Size of grains in samples of sand from partial section on Oil Creek.

Mesh. / No.	40	60	80	100	200	Pan.	Total.
A20	2.18a	5.71	27.49	37.48	24.9	2.22	99.98
A21	2.78	15.97	43.02	25.51	12.72	.03	100.03
A22	2.55	22.32	47.5	20.59	7.04	.04	100.02
A23	5.19	7.51	20.64	28.63	36.48	1.54	99.99
A24	10.01a	14.89	34.67	21.93	15.33	3.15	99.98
A25	1.6	13.55	45.88	25.31	12.41	1.24	99.99
A26	3.85	24.89	38.75	25.68	6.42	.43	100 02
A27	4.9	33.18	35.18	17.25	9.34	.17	100.02
A28	3.96	19.97	39.6	22.68	13.29	.47	99.97

a. Most of this can be mashed up finer between the fingers.

Mill Creek section (No. A5).— The last section studied in the southern belt is on Mill Creek in sec. 32, T. 3 S., R. 5 E. The structure in this section is slightly complicated and the thickness of the different beds could be only approximated, as the dip of the rocks varies from 30° to 90° and in a few places are slightly overturned. No attempt was made to deal with the upper beds because they are poorly exposed. The following section was made:

Partial section of the Simpson formation on Mill Creek.

			Glass sand. Feet.	Total. Feet.
Middle Beds.	22.	Impure sandstone, with shale and limestone interbedded		10
	21.	Massive, white sand	15	15
	20.	Irregular sandstones		4
	19.	White sand	2	2
	18.	Impure sand		4
	17.	White glass sand	12	12
	16.	Limestone		22
	15.	Impure sandstone		5
	14.	Pure white sand	45	45
	13.	Impure sandstone		10
	12.	Shales and limestones, with two thin ledges of sandstone..		505
Lower Beds	11.	Thin seams of shale, limestone, and sandstone		27
	10.	Good white sand	30	30
	9.	Impure sand and shale		10
	8.	Good glass sand	15	15
	7.	Sandstone with thin seams of shale and limestone		20
	6.	Shale and limestone		650
Basal Beds.	5.	Impure sandstone, with interbedded shale and limestone ...		11
	4.	Solid, massive, white sandstone of good quality	50	50
	3.	Rather impure sandstone, good only for bottles		11
	2.	Massive, white sand, apparently of good quality	13	13
	1.	Sandstone grading downward into shaly limestone		5

No samples from the Mill Creek section were taken because the nature of the exposure renders the obtaining of representative samples rather difficult. The location of the deposits with respect to transportation facilities, and the rugged character of the country renders the utilization of these deposits unfeasible.

The following table gives a summary of the results obtained from the five sections made at different localities in the Southern Belt area, the thicknesses being given in feet:

Section.	Phillips Creek.		Cool Creek.		Crusher.		Oil Creek.		Mill Creek.			
Horizon.	Total thickness.	Thickness of glass sand.	Total thickness.	Thickness of glass sand.	Total thickness.	Thickness of glass sand	Total thickness.	Thickness of glass sand	Total thickness.	Thickness of glass sand	Average thickness of sand horizon.	Average thickness of glass sand.
Upper Beds.	69	18	91	91?	197	58	65	?	?	?	105	55
Middle Beds	167	66	83	53	54	42	248	115	129	74	136	70
Lower Beds......	174	12	97	67	100	86	45-100	?	102	45	108	53
Basal Beds.							101	76	90	63	95	70

Although the ledges are almost on edge and many sharp exposures were seen where the streams have cut their way across the beds, yet it was impossible in every case to determine the exact thickness of the sand or to judge its quality definitely. As an example the upper beds are not prominent in the southeast part of the belt and in the sections on Oil Creek and Mill Creek the beds are concealed beneath the soil and hence the quantity and quality of the sand could not be determined, although indications are that they contain as much sand which is of as good a quality as that shown in the other sections. In the last two sections the basal beds stand out the most prominently. They occur locally in the western end of the belt, and usually outcrop as a thin ledge of sandstone containing a large per cent of lime.

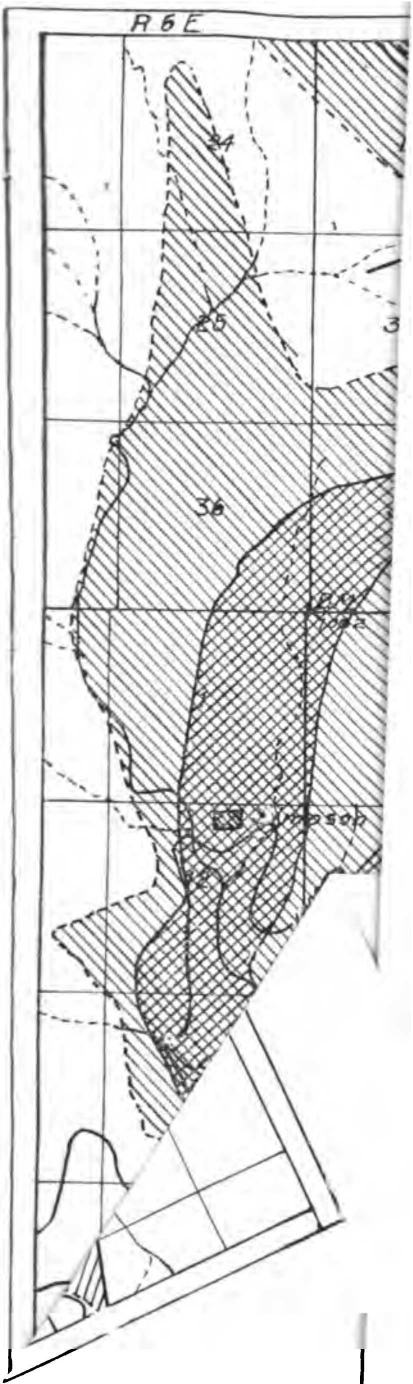
None of the horizons are constant, but the variation in the total thickness in the different localities is partly due to the arbitrary division lines separating the sand ledges from the limestones and shales above and below; since in most cases there is a more or less gradual gradation from one to the other.

Delaware Creek Area.

General features.— The Delaware Creek area consists of the greater part of T. 1 S., R. 7 E., with an arm which extends north into T. 7 N., R. 6 E. The outcrop in T. 1 S., R. 7 E., is approximately square and occupies an area of about 25 square miles, while the arm to the north is about 5 miles long and 3 miles wide, making a total area of about 40 square miles (Pl. II).

The glass sand of the Delaware Creek area is comprised in the Simpson formation. This occurs in a comparatively flat basin, bounded on the east and north by the rounded knobs of the Viola limestone, and on the west by the rolling plateau of the Arbuckle limestone. The general slope is to the east. On the south side where the formation is 5 miles wide the dip is about 3° east, while in the northwest, where it is 3 miles wide, the dip is about 10° to the east. In section 29, and for 3 miles to the northeast, the width of the outcrop is not so great and in places is not more than one-half mile. The dip in this vicinity is 20° to 45° to the southeast.

As shown on the map of the region, a fault occurs in the northeast part of the area, the lower horizon of the Simpson being faulted into contact with the Viola limestone. This fault coupled with erosional features causes a tongue of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Viola to protrude 3 miles southward, dividing the Simpson outcrop. The basal beds are exposed along the western border of the Simpson formation and along the stream in the extreme southern part of sec. 15, T. 1 S., R. 7 E. The lower beds have wide outcrops in the valley and to the east of Blue River. In the western part of the area also the lower beds are widely exposed along Little Blue Creek. This area is probably continuous with the wider area to the southward but it is not mapable. The middle and upper beds outcrop between Little Blue Creek and the Viola limestone to the eastward.

Considerable crumpling in the members of the formation is seen in the east-central part of sec. 29, T. 1 S., R. 4 E., where the dip suddenly increases. The crumpled area is small and, beginning in the north-central part of sec. 29, and continuing northward, there is no irregularity in the arrangement of the members of the formation, and the four horizons of sand except in that portion of the area north of the base line are well exposed.

The large deposits of glass sand in the Delaware Creek area cannot be developed at present, because there are no transportation facilities. The nearest means of transportation is a branch line of the Missouri, Oklahoma, and Gulf Railroad. It is reported that plans are being laid to extend the branch line from Bromide on to the northwest. Unless these plans materialize, the large deposits of good glass sand in this region must remain undeveloped. The four miles intervening between Bromide and the sand bluffs along Delaware Creek is comparatively smooth and the road could be built at moderate cost. None of the glass sand deposits of this area, except those in the extreme northwest part, are inaccessible, but there is very little probability that any of it will be developed except the glass sand bluffs along Delaware Creek, since these are more accessible and contain an inexhaustible supply of easily workable sand and are near water.

Occurence and character of sands. — The glass sand in the Simpson formation in the Delaware region occurs in four beds or series of beds which are very similar in most respects to those found in the sections on Mill Creek, Oil Creek, Phillips Creek, and near Crusher.

The *basal beds* are found resting on the Arbuckle limestone along the western border of the Simpson formation. In the nortwest part of sec. 36, T. 1 S., R. 6 E., the outcrop runs northeastward and disappears under Blue River and ap-

parently the beds do not again appear until in the north-central part of sec. 22, T. 1 S., R. 7 E. The prevailing evidence is that the bluff of sand north of the school house in the southern part of sec. 15, T. 1 S., R. 7 E., is a part of the basal beds, since it occurs about 660 feet stratigraphically underneath the lower beds as in the sections on Oil Creek and Mill Creek; and since the characteristics of the sand ledge and the immediately overlying limestone and shale are similar to those in those sections. The beds extend to the southwest a short distance and disappear. The sand in this area is inconveniently located for development.

The basal beds were not mapped in any of the areas studied because with only a single exception, which is noted above, the beds wherever they occur at all are always found outcropping on top of the exposed Arbuckle limestone.

On the bluff mentioned above occurring in sec. 15, T. 1 S., R. 7 E., the following succession was observed (*section No. B1*):

	Feet.
2. Limestone and shale	25
1. Sandstone, base not exposed	18

The analyses below show the quality of the sandstone, sample B1 coming 2½ feet; B2, 7 feet; and B3, 14 feet from the top:

Analyses of samples of sand from section No. B1.

No.	Fe_2O_3	Al_2O_3	CaO	MgO	SiO_2	Organic matter.
B1	.112	.228	.135	.0453	99.388	.0027
B2	.154	1.6	.112	.059	97.986	.0041
B3	.168	.242	.135	.099	99.256	.004

Size of grains of samples of sand from section No. B1.

No. \ Mesh.	40	60	80	100	200	Pan.	Total.
B1	.12	8.74	54.82	20.02	15.51	.82	100.03
B2	.27	1.94	36.35	36.17	24.27	1.03	100.03
B3	.62	7.88	37.17	30.42	23.22	.71	100.02

The boundary lines of the outcrop of the *lower beds* are somewhat indefinite. The beds are apparently separated into two divisions. The upper part passes east of Pilgrim Chapel and an exposure on a small branch in the northeast part of section 33 shows it to be about 10 feet thick. The top 2½ feet is almost black with carbonaceous material, but

this is only a local occurrence, since in the other exposures of this ledge the carbonaceous material is not prominent. The lower division passes to the west and north of Pilgrim Chapel. In the northeast of sec. 5, T. 2 S., R. 7 E., it is divided into several thin beds of sandstone interstratified with thin layers of limestone. Sample B 4 was taken from one of these beds which is 2½ feet thick.

Analysis of sample of sand from N. E. 1-4 sec. 5, T. 2 S., R. 7 E.

No.	Fe_2O_3	Al_2O_3	CaO	MgO	SiO_2	Organic matter.
B4	.434	.596	.175	.065	98.592	.0082

Size of grains of sample of sand from N. E. 1-4 sec. 5, T. 2 S., R. 7 E.

Mesh. / No.	40	60	80	100	200	Pan.	Total.
B4	.95	3.56	20.12	31.1	41.62	2.64	99.99

The quality of this sand together with its thickness and location makes it infeasible for working.

A sand bed is exposed in the bank of a small ravine 200 yards southeast of the center of section 32. The thickness of the sand is unknown, but there is probably 10 feet of it, as a 10 foot exposure on the same ledge is shown 460 yards north and about 50 yards east of the center of section 27.

On the south the entire lower beds outcrop over most of sec. 5 and the eastern part of sec. 6, T. 2 S., R. 7 E., and extend just across Blue River to the west. The general direction is to the northeast and the beds pass under the Viola limestone in the north-central part of sec. 14, T. 1 S., R. 7 E.

The outcrop of the *middle beds* begins in the east-central part of sec. 3, T. 2 S., R. 7 E., and runs north to the north-central part of sec. 23, T. 1 S., R. 7 E., where they disappear by pinching out or by faulting. They parallel those of the upper beds but are not nearly so conspicuous, since Delaware Creek crosses them and a good part of the sand is concealed in sections 27 and 34. Along the west side of the outcrop the sand is found in several small knobs which are capped by outliers of the limestone that separates the upper and middle beds. This limestone formerly extended over the area now occupied by Delaware Creek and passed under the upper beds to the east. The removal of this limestone by Delaware Creek has exposed portions of the sand east of the original outcrop. The sand in this locality is not so accessible as is that in the upper beds and no good fresh ex-

posures were seen. In the eastern part of sec. 27, the outcrop leaves the valley and frequent exposures are seen from this point northward. Two hundred and seventy yards east of the northwest corner of sec. 26, 6 feet of white, friable sand of the middle beds is exposed (sample B5). The base of the sand is not seen but indications are that it lies several feet below the base of the exposure. It must be borne in mind that in the five sections of the Simpson, in the southern area above discussed, where the thickness could be more or less accurately determined, the middle beds show from 42 to 115 feet of glass sand.

Analysis of sample from sec. 26, T. 1 S., R. 7 E.

No.	Fe_2O_3	Al_2O_3	CaO	MgO	SiO_2	Organic matter
B5	.056	.277	.11	.068	99.406	.0014

Size of grains of sample from sec. 26, T. 1 S., R. 7 E.

No. \ Mesh.	40	60	80	100	200	Pan.	Total.
B5	.7	10.8	51.8	21.1	14.	1.5	99.99

As may be seen from the above analysis this is a very pure sand and only lacks transportation facilities to make it valuable.

The *upper beds* outcrop along the east side of the area. Beginning in the west-central part of sec. 2, T. 2 S., R. 7 E., they run almost due north and disappear either by faulting or by pinching out 480 yards west and 355 south of the center of sec. 23, T. 1 S., R. 7 E. The width of the outcrop varies from 100 to 500 yards and in sections 26 and 35 the outcrop is prominent and only a few small ravines cut the surface; while in section 2 the beds are less prominent and Delaware Creek has deposited alluvium over a good part of them.

Limestone caps the beds and forms a rather prominent ridge on the east side of their outcrop, while the limestone and shale on the west side that separate the upper and middle beds are frequently eroded down by small streams cutting their way across to Delaware Creek, and in most of these places the sand is covered with the soil. In a few small areas sand from the upper beds has been deposited over the limestone and shale in these localities and gives the surface the appearance of one of the series of sand beds. A sufficient number of rounded limestone knobs remain, however, to enable one to determine the boundaries of the sandstone horizons.

The following section from the glass sand bluff of Delaware Creek, 355 yards east and 255 yards north of the southwest corner of sec. 35, T. 1 S., R. 7 E., gives an estimate of the quantity of glass sand in the upper beds and the analyses show the quality:

Partial section of upper beds of Simpson formation on sec. 35, T. 1 S., R. 7 E. (No. B2.).

		Glass sand. Feet.	Total. Feet.
9.	Limestone and impure sandstone capping bluff		10-25
8.	Massive, white, friable sand...	21	21
7.	Thin, irregular, siliceous limestone containing a large per cent of iron		½
6.	Sand similar to No. 8 in appearance	4	4
5.	Siliceous limestone		3
4.	White, friable sand	4	4
3.	White sandstone, rather hard	2	2
2.	White, friable sand	5	5
1.	Impure sand and thin layers of shale and limestone.........		16

Analyses of samples from a partial section of Simpson formation in sec. 35, T. 1 S., R. 7 E.

No.	Fe_2O_3	Al_2O_3	CaO	MgO	SiO_2	Organic matter.
B6	.126	.464	.31	.0246	98.82	.01
B7	.182	.551	1.35	.0337	96.81	.0091
B8	.406	.61	1.512	.088	96.184	.012
B9	.07	.163	7.5	.03	86.287	.0064
B10	.112	.141	4.125	.0282	92.377	.0042

Size of grains of samples from a partial section of Simpson formation on sec. 35, T. 1 S., R. 7 E.

Mesh. / No.	40	60	80	100	200	Pan.	Total.
B6	1.6	8.4	24.2	23.1	38.12	4.6	100.02
B7	2.58	12.61	35.16	25.4	23.02	1.24	100.01
B8	2.69	13.55	40.1	22.545	18.82	2.22	99.975
B9	1.76	35.59	44.2	12.42	5.41	.62	100.
B10	1.6	13.25	50.2	20.5	12.27	2.2	100.02

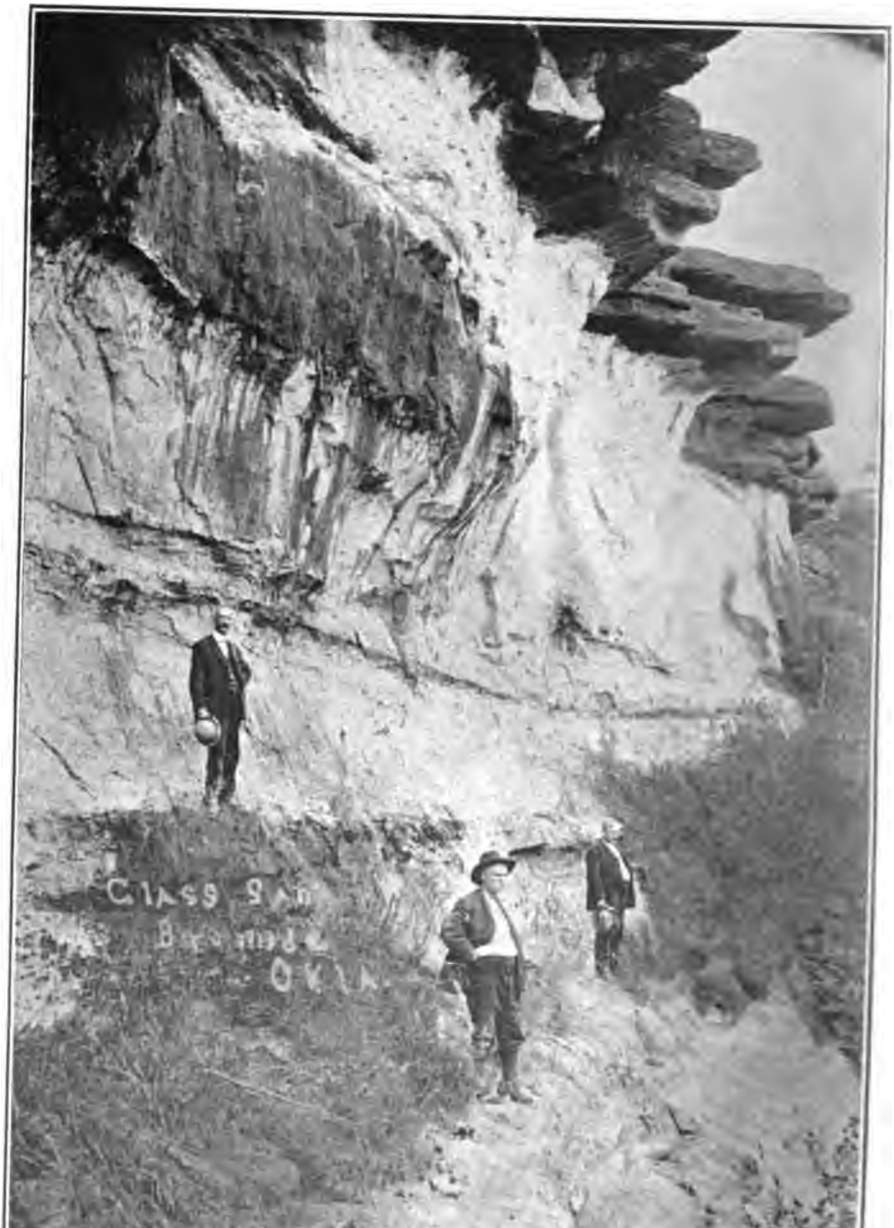


Plate III.

The bluff of sand outcrops for about 100 feet along the east bank of Delaware Creek and sufficient water for washing out the impurities of the sand is found at the base of the bluff (Pl. III). The outcrop is capped with several feet of limestone, the dip of which is about 10° to the east. The 21-foot bed of sand in this bluff is sufficiently pure, according to the amount of impurities allowed for different grades of glass as shown in table on page 11, for any but the best grades of glass. There are several places in the two miles on north from this bluff, where by the removal of a few feet of surface soil, deposits of sand as good as the above may be opened up at a small expense. In fact there is very little of the upper beds in the three miles that cannot be easily worked, except on the south side in section 2, where Delaware Creek has deposited alluvium over a large part of the beds. These deposits on the north, however, are not so conveniently located since there is no water near them.

Roff Area.

General features.— This area extends eastward from Roff through the east central part of T. 2 N., R. 4 E., and onward to the eastern limit of T. 2 N., R. 5 E. The outcrop of the Simpson formation forms a belt from one-half to one and one-half miles wide (Pl. IV). Between this area and the Delaware Region to the southeast most of the Simpson is faulted out and in the northeast part of T. 2 N., R. 6 E., it is entirely gone and the Viola limestone is brought down into contact with the Arbuckle limestone.

The Simpson formation in the Roff area occurs in a narrow valley between the Viola limestone on the north and the Arbuckle limestone on the south. It is almost on edge. Little relief is shown, except that the limestone between the middle and lower beds forms a low ridge near the middle of the outcrop, the sandstone beds lying in narrow valleys on either side.

In the western part of sec. 14 a fault cuts out most of the formation. All of the upper and most, if not all, of the middle beds are faulted out. Another fault on the south in secs. 23 and 24 limits the formation in that direction. Along this fault the basal, and in most places the lower, beds have been faulted up and eroded away. Between Roff and Fitzhugh the Simpson is concealed beneath a formation of sandstone and shale of Carboniferous age.

Occurrence and character of sand. — The glass sand in the Simpson formation in the Roff region also occurs in four

series of beds but for reasons given later, it is probable that only the basal beds will be developed in the near future.

The *basal beds*, resting as they do directly on the Arbuckle limestone, outcrop just to the north of it in the Roff area. In the creek bottom east of Roff the outcrop widens out and the sand is found underlying the south half of secs. 17 and 18. In the southwest part of sec. 18 the ledge swings to the south and outcrops to the east of Roff and in a short distance disappears under the sandstone and shale of the Carboniferous.

The St. Louis and San Francisco Railroad passes over a portion of the basal beds in sec. 18 and with little expense a spur can be run to any other part of the remainder in the two sections. The sand is overlaid by 2 to 6 feet of alluvial soil which may be removed at low cost.

A small quarry has been opened up in the bank of the creek on the south side of sec. 18. From this a sample of sand was obtained which gave the following results:

Analysis of sample of sand from basal horizon near Roff.

No.	Fe_2O_3	Al_2O_3	CaO	MgO	SiO_2	Organic matter.
C1	.28	.988	.13	.032	98.24	.229
C1a	.252	.59	.09	.028	98.872	.104

Size of grains of sample of sand from basal horizon near Roff.

No. \ Mesh.	40	60	80	100	200	Pan.	Total.
C1	1.74	17.	36.58	22.58	20.785	1.35	100.035

In the above analysis C1 was unwashed, while C1a was washed, by simply putting the sample in water, letting it remain an hour, draining and drying. The results of the analysis show that most of the impurities may be removed by washing. As Blue Creek does not run the year round, the supply of water would have to be secured from wells or reservoirs.

A carload of this sand was tested by Mr. M. W. Conway, Superintendent of the Tulsa Glass Company, at the plant of the company. The results show that the glass made from this sand is of a better quality than that made from the sand his plant received from the St. Louis region.

Since the sand is accessible to transportation and is of a good quality, the remaining factor that determines its value is the amount of sand in the deposit.

The thickness of the basal beds in secs. 17 and 18 has not been determined, since they are covered in the creek bottom and no structure is seen at this point. The beds are sharply exposed, however, in the northwest corner of sec. 22, and show that they are comprised of three divisions. The bottom 35 feet is composed of massive sand, the next 28 feet is shale, limestone, and sand, and the top 35 feet is massive sand. The surface of these beds is weathered so that fresh samples could not be obtained.

It is unlikely that the thickness of the basal beds has changed materially in the distance between secs. 22 and 19. If this is true and if the quality is as good as shown in the above analysis either one of the 35 foot beds contains a vast amount of good sand.

The *lower beds* are found outcropping along the south side of the limestone ridge that separates them from the middle beds. Their location and extent are shown in the accompanying map (Pl. IV). The conditions found in the upper and middle beds also prevail here and consequently the sand is not workable.

The *middle beds* parallel the upper and pass under the Carboniferous near the northwest corner of sec. 16. The same conditions found with reference to the upper beds obtain also in the middle beds.

The *upper beds* are exposed for a distance of about 1½ miles northwest and southeast. On the east side they are faulted out in the southern part of sec. 14 and on the west they pass under the Carboniferous area near the half-section line on the north side of sec. 16. The beds are almost on edge in places and are hardly treaceable. They are prominent near the center of this section and slight exposures are seen in the ravine running east. The sand in the beds can never be worked at a profit because in addition to its being buried beneath several feet of soil, drainage conditions are bad and the beds are on the edge in the bottom of the ravine.

From the above considerations it will be seen that the sand in the lower, middle, and upper beds of the Roff area is not of the highest value. While no analyses are given conditions of quarrying with respect t ostripping, drainage, and attitude of the beds render the deposits valueless under present conditions. With respect to the basal beds condi-conditions of quarrying with respect to stripping, drainage, grade, and while, as stated above, the amount of sand present could not be precisely determined such evidence as

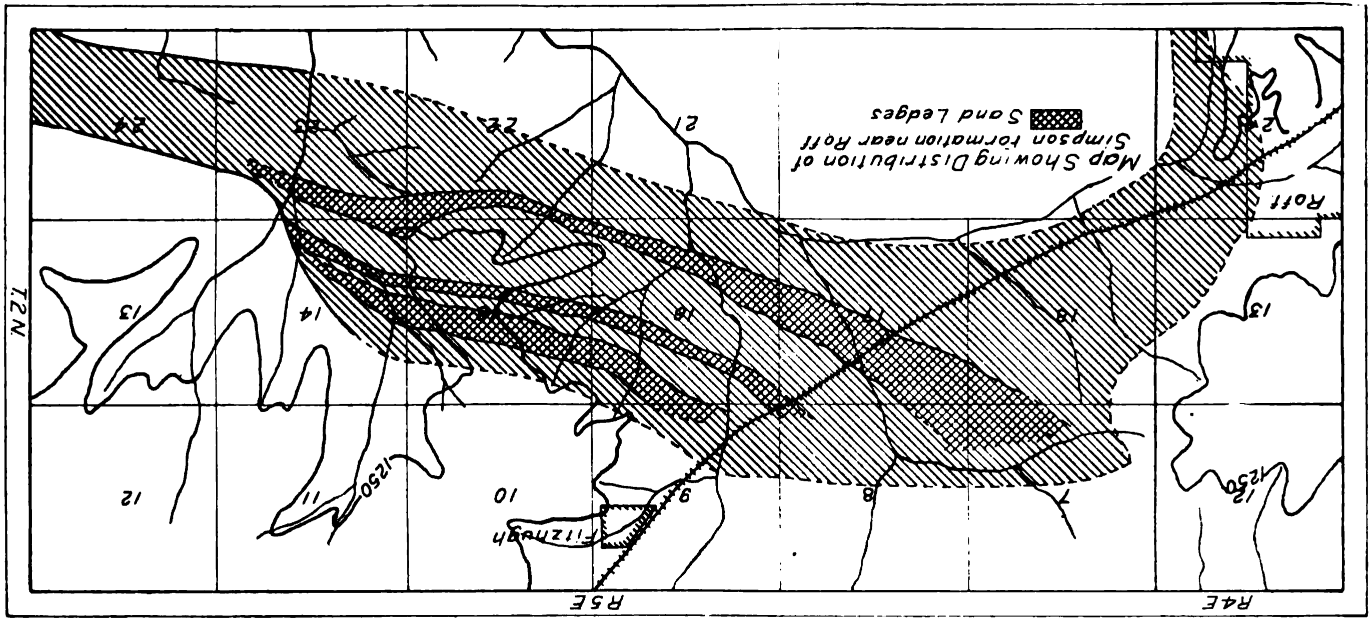

Map Showing Distribution of
Simpson formation near Roff
Sand Ledges
T2N
R5E
R4E
Fitzhugh
Roff
1250

Plate IV.

could be obtained indicates a large amount occurring under rather favorable conditions.

Hickory Area.

General features.—This area, comprising about seven square miles, is located near the center of T. 1 N., R. 4 E. The village of Hickory on the St. Louis and San Francisco Railroad is located on the east border of the area .

The exposed area of the Simpson formation is here bounded on the north, east, and south by the Arbuckle limestone, and on the west it is limited by sandstone and shale of Carboniferous age. Faults limit the area on every side except the west and one fault traverses the area in the north-central part. This faulting, coupled with poor exposures renders the determination of the amount of sand present and the stratigraphic position of the beds unsatis factory. The Simpson formation outcrops in this area in a comparatively flat basin which is only slightly dissected by Mill Creek and its small tributaries.

Occurrence and character of sands.— A bed of sand outcrops along the north line of secs. 14 and 15. A sharp exposure is seen about 250 yards southwest of the half-mile stone on the north side of the latter section. At this place it is 25 feet thick. Sample D1 is a representative of the top 15 feet, and D2 of the bottom 10 feet. The hard siliceous limestone capping the sand bed dips 10° to the north. The bed is not prominent at any other place. To the west the bed is covered in the bottom of Mill Creek, and to the east it runs in a little valley and is covered by several feet of surface soil that has been washed down from the ridge on the north. The prospects for the devolpment of this bed are unfavorable, because it is not easily accessible and only the top 15 feet is sufficiently pure to be used.

In the little valley just south of the cotton gin in Hickory another thin bed is found. This also is covered with surface soil. Its thickness is unknown but the evidence obtainable indicates but a few feet. The sand contains a large per cent of impurities but most of these may be removed by washing. Wells dug in the south-central part of secs. 14 and 15 show several feet of white sand, but since this occurs 50 feet or more beneath the surface it is valueless.

Along the north and south sides of the area the fine-grained, generally friable sandstone of the basal beds has been altered to a quartzite. This alteration is often observ-

ed in the basal horizon and is prominent at Roff, Mill Creek, and the other localities where the beds are sharply exposed. This alteration is apparently due to solution and the re-deposition of secondary silica between the grains and is a result of weathering.

The following analyses show the character of the sand in the area:

Analyses of samples of sand from near Hickory.

No.	Fe_2O_3	Al_2O_3	CaO	MgO	SiO_2	Organic matter.
D1	.112	.11	2.637	04	94.56	.486
D2	.056	.097	16.27	.098	70.554	.32

Size of grains of samples of sand from near Hickory.

No. \ Mesh.	40	60	80	100	200	Pan.	Total.
D1	.88	4.35	29.86	27.91	34.74	2.24	99.98
D2	5.91	14.54	32.12	24.24	19.45	3.72	99.98

Mill Creek Area.

This area includes two detached parts which for purposes of discussion will be conveniently designated as the lower and upper parts respectively.

The *lower part* consists of a relatively narrow band extending from the north-central part of T. 2 S., R. 4 E., eastward across Mill, Rock, and Pennington creeks into the west-central part of T. 2 S., R. 6 E. Its continuity is broken in several places by faults. From the western limit eastward to Rock Creek the basal and lower beds are faulted out. In the narrow strip between Rock and Pennington creeks only the upper beds are present, the other three being faulted out. At the extreme eastern end of this part of the area the entire Simpson formation is present, but it is poorly exposed and few details could be obtained.

In that part of the lower area lying west of Rock Creek the middle and upper beds are exposed, but they are not accessible and therefore are not of any present value, except in sec. 18, T. 2 S., R. 5 E., where the St. Louis and San Francisco Railroad crosses the upper and a portion of the middle beds. West of the railroad both series of beds are exposed. They contain approximately the same amount of sand as the middle and upper beds in the Southern Belt and the quality of the sand is as good as in that area, and in addition to the

accessibility of the sand, little stripping is required.

The *upper part* of the Mill Creek area lies in the northwest corner of T. 2 S., R. 5 E., being roughly semi-circular in outline and embracing an area of about 2½ square miles. Only the basal beds are present, the others being eliminated by faulting. About one-half mile northeast of the town the sand outcrops in low bluffs along the banks of a small ravine for three to four hundred yards. From one of the bluffs several tons of sand have been removed. At this place 15 feet of sand is seen, the base not being exposed, but the indications are that the bed continues several feet below the base of the exposure. The quality of the sand is shown by the following analysis:

Analysis of sample of sand from one-half mile northeast of the town of Mill Creek.

No.	Fe_2O_3	Al_2O_3	CaO	MgO	SiO_2	Organic matter.
E1	.35	.56	.065	.188	98.782	.008

Size of grains of sample of sand from one-half mile northeast of the town of Mill Creek.

No. \ Mesh.	40	60	80	100	200	Pan.	Total.
E1	.16	2.38	24.34	32.18	37.52	3.4	99.99

These beds lie one-fourth mile from the St. Louis and San Francisco Railroad, and since practically no grading will be required to run a spur out to the beds they are easily accessible.

Good exposures of the basal beds are also seen in a small creek 1½ miles east of town. The sand here is of the same quality as that northeast of town. It is accessible and the St. Louis and San Francisco Railroad has a spur out to some gravel beds southeast of Mill Creek which passes within three-quarters of a mile of the sand deposits.

Nebo Area.

General features.—This area derives its name from Nebo Post Office which is situated near the western border. It consists of approximately 12 square miles and is located principally in T. 2 S., R. 3 E. It extends south a short distance in T. 3 S., and northeast a short distance into R. 4 E. It is roughly rectangular in outline being approximately 6 miles long north and south and 2½ miles wide east and west (Pl. V).

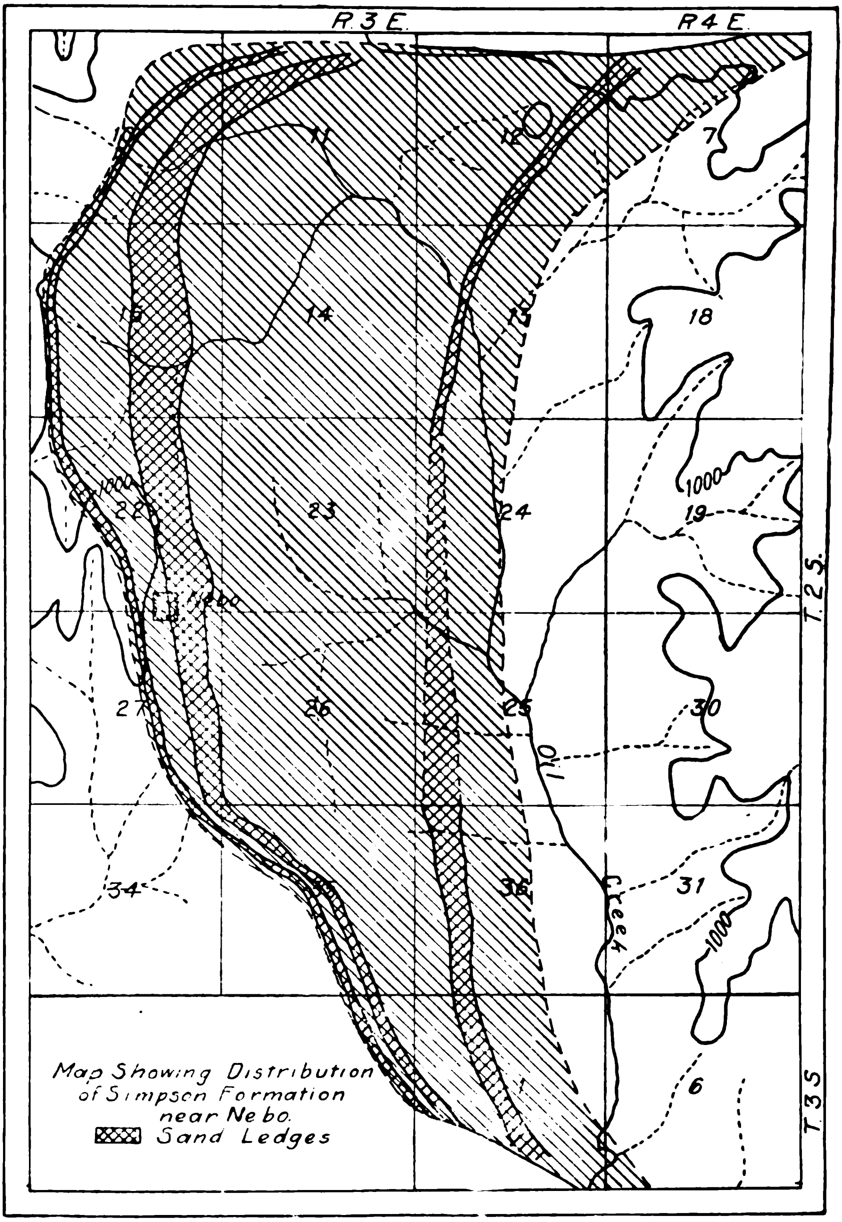

R.3 E.
R.4 E.
T.2 S.
T.3 S.
1000
Nebo
Oil Creek
Map Showing Distribution of Simpson Formation near Nebo.
Sand Ledges

Plate V.

In the vicinty of Nebo the Simpson formation outcrops in the wide, flat valley of Oil Creek. In the eastern half of the area the formation is concealed beneath a thick mantle of soil.

At Wyatt on the southeastern extremity of the area the outcrop of the formation has ben cut off by a fault. In the northeast also it is terminated by a fault. In the central part of the area the dip is about 10° to the west while to the north and south it is somewhat greater but very variable.

Occurrence and character of sand. — The workable glass sand in this region occurs in the lower, middle, and upper beds. The basal beds for the most part are concealed beneath the alluvium of Oil Creek. An exposure in the southeast part of sec. 36 shows 60 feet of impure sand. As has been mentioned, the area is of low relief and there are no bluffs or sharp exposures of either the middle or upper beds. For this reason no samples were taken from these beds. But in the south-central part of sec. 36 a ravine cuts at right angles across the lower beds giving a fresh exposure. Along this ravine the following section was made:

Section of lower beds in sec. 36, T. 2 S., R. 3 E.

	Glass sand. Feet.	Total. Feet.
8. Massive, white sand, similar to No. 1	33	33
7. Impure sandstone		15
6. Shale, limestone, and sandstone..		30
5. Massive, white sandstone	41	41
4. Impure sandstone		4
3. Massive, white sandstone	30	30
2. Impure sandstone		4
1. Massive, white sandstone	23	23

The dip could not be determined accurately as the rocks were slightly crumpled. The rocks just below the sand beds show a dip of 21° to the west and the thickness of the beds was calculated on this basis.

A composite sample gathered from different places in Nos. 1, 3, 5, and 8 in the section above gave the following analysis:

Analysis of sample of sand from lower beds in sec. 36, T. 2 S., R. 3 E.

No.	Fe_2O_3	Al_2O_3	CaO	MgO	SiO_2	Organic matter.
F1	.014	.136	.15	.077	99.49	.008

Size of grains of samples of sand from lower beds in sec. 36, T. 2 S. R. 3 E.

Mesh. / No.	40	60	80	100	200	Pan.	Total
F1	.41	6.96	33.31	34.12	24 83	.39	100.02

Although the outcrop is in a flat level region, it is sur rounded by a rough hilly country, and is almost an isolated area . The nearest transportation facilities offered is the Gulf, Colorado, and Santa Fe Railroad, 4 miles west. On account of the rugged character of the country it is alto gether unlikely that any railroad will be built to it in the near future.

Sulphur Area.

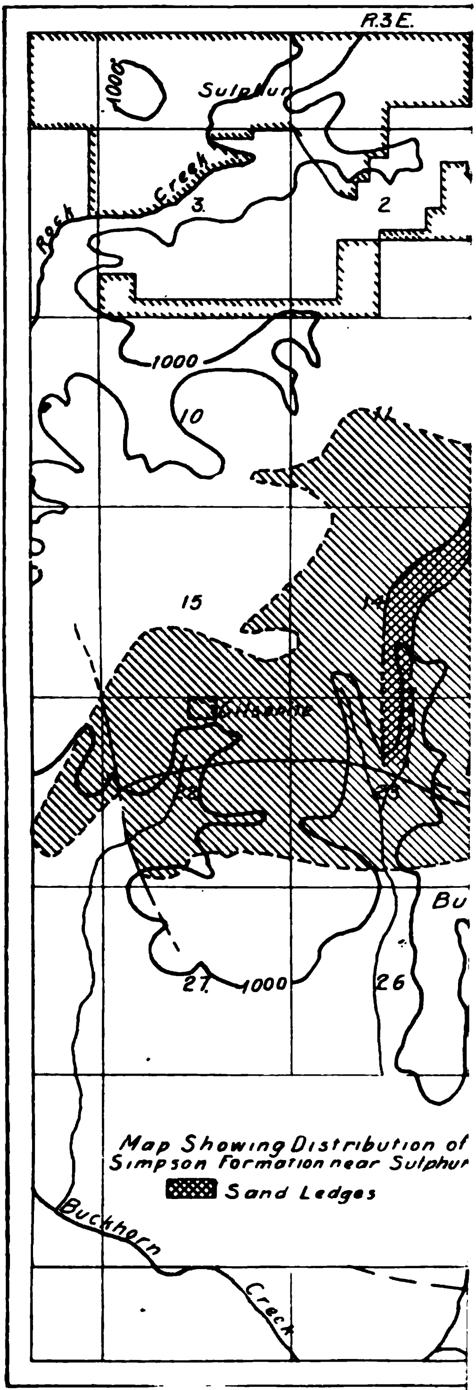
The Sulphur area lies south and southeast of the town of Sulphur being located almost wholly in T. 1 S., Rs. 3 and 4 E. It is rather sharply subdivided, chiefly by faulting, into three smaller divisions, which may be designated as a, b. and c, which are shown in the accompanying map (Pl. VI).

Division a is located in the southeastern part of the general area and lies in the southwest corner of T. 1 S., R. 4 E., but extends also about one-half mile south into T. 2 S.

On the north the Simpson formation is faulted against the Arbuckle limestone and on the south it is faulted into contact with the Caney shale and Glenn formation. A small fault occurs on the west side, but does not affect the beds of sand. Although the Simpson formation contains a large quantity of good glass sand, yet because it is inaccessible it cannot be worked at present. The beds are not prominent and no bluffs or sharp exposures were seen. They are largely covered with surface soil washed down from other members of the formation.

Division b is located in the east-central part of T. 1 S., R. 3 E. The accompanying map gives the distribution of series of beds and the extent of their outcrops. On the north and west the Simpson passes under the Franks conglomerate. On the south it is cut off abruptly by a complex fault. Eastward it is limited by the Arbuckle limestone.

The surface of this division is broken and hilly and several sharp exposures of the beds are seen along the steep banks of the ravines. Although these beds contain a large amount of pure sand which can be easily worked, yet in all probability they will not soon be reached by railroad and are therefore without value at present.


R.3E.
1000
Sulphur
Rock Creek
3
2
1000
10
11
15
27
1000
26
Bu
Map Showing Distribution of
Simpson Formation near Sulphur
Sand Ledges
Buckhorn Creek

Division c lies in a crescent shape in the northeast part of T. 1 S., R. 4 E., and is really a continuation of Division b. On the west the area is bounded by the Viola and on the south by the Arbuckle limestone. On the northwest the Simpson passes beneath the Franks conglomerate. The surface of the area is level and the beds do not stand out prominently. They stand on edge and are covered by surface soil. All things considered they cannot be worked at a profit at present.

The basal part of the Simpson extends 7 miles to the east beyond the limits of the accompanying map. The formation lies nearly horizontal and the basal beds of sandstone, after being mixed with the surface soil, contain too large a per cent of impurities to be used for anything but the poorest grades of bottles. Although crossed by the St. Louis and San Francisco Railroad these beds, on account of the valuable deposits elsewhere in the Arbuckle Mountains, are without value at present.

Davis Area.

This area is located on the northeast slope of the Arbuckle Mountains in the valley of the Washita River. The exposures occur in three separate localities; on Coburn Creek, on Falls Creek, and on the Dougherty anticline.

On *Coburn Creek* (called also Colbert Creek) 5 miles southwest of Davis, the Simpson formation outcrops on the northeast slope of the mountains west of Washita River. Coburn Creek and its tributaries have deeply dissected the region so that it is very rugged, rendering it almost inaccessible.

The area is on the northeast limb of the Arbuckle anticline and the rocks dip in general 60° to 80° to the northeast, but are much folded and faulted. The Simpson formation is exposed in the western part of the area, dips northeast beneath the Viola limestone, reappears by an anticline, again dips northeast beneath the Viola to reappear along the southern end of a north-south fault, the rocks on the west and south sides respectively having dropped.

In the Coburn Creek exposures as in the Davis area in general the Simpson is much thinner than in other parts of the mountains. This is because the basal beds of sand and a considerable part of the basal limestone and shale are absent. The formation on the whole is more siliceous than in other places, and the upper and middle beds of sand are thicker than usual. The sand is of good quality and occurs

in large quantities, but it is of no present value, because the region cannot be easily reached by railroad, owing to the rugged surface of the country.

The second subdivision of the Davis area is best seen on *Falls Creek* on the west side of the Washita River, 6 miles due south of Davis. A long, narrow, faulted strip of the Simpson formation outcrops in the southeastern part of this area northwest of Dougherty. The Simpson formation here is faulted against the Arbuckle limestone on the southwest resulting in a long narrow outcrop extending northwest-southeast between the fault and the outcrop of the Viola limestone. The middle and upper beds only are exposed. Although a large quantity of good glass sand is exposed in this area and is only a mile from railroad, it is not probable that it will be soon developed owing to the fact that the Washita River intervenes between the deposit and the railroad.

The third part of the Davis area is in the central part of sec. 21, T. 1 S., R. 2 E., where a narrow band of the Simpson extending northwest-southeast, is exposed along the axis of the *Dougherty anticline*. The northwest end is adjacent to the Gulf, Colorado, and Santa Fe Railroad. The beds dip at a high angle. The sand is of good quality, and occurs in large quantities in the upper and middle beds. Only a part of the lower beds is present. Although the topography is somewhat rough and a few small streams traverse the formation, yet large amounts of the sand may be given transportation facilities, which is the chief factor in determining the value of the glass sand deposits in the Arbuckle Mountains.

SOUTHEASTERN OKLAHOMA.

Trinity Sand.

General Features.

The second area in which glass sand occurs in quantity in Oklahoma is in the southeastern part of the State. The formation containing it is known as the Trinity sandstone which is the basal formation of the Cretaceous system exposed in this area. The other formations from the Trinity up are the Fredericksburg, Washita, Dakota and Colorado.

The Trinity sandstone enters Oklahoma from Texas just west of Marietta and extends north and east to near Ardmore, thence generally eastward into Arkansas, outcropping as a broad band five to fifteen miles wide along the southern base of the Arbuckle and Ouachita mountains

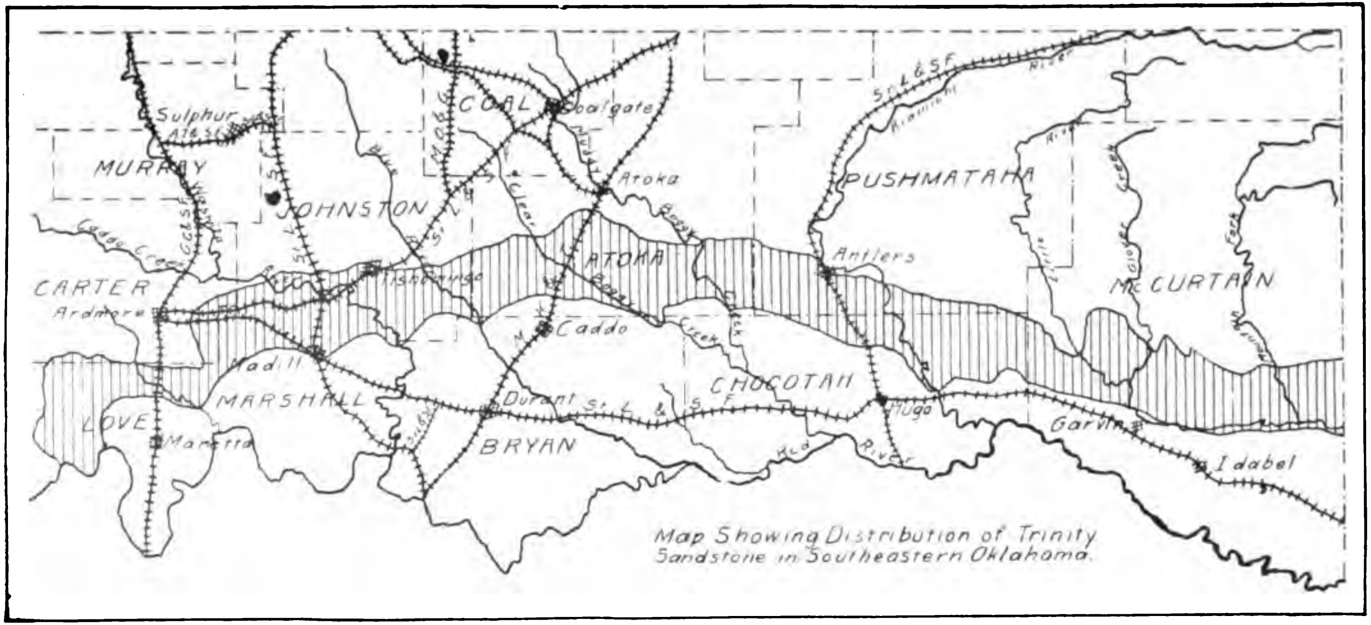

MURRAY
Sulphur
JOHNSTON
COAL
Coalgate
Atoka
ATOKA
PUSHMATAHA
Antlers
McCURTAIN
CARTER
Ardmore
Tishomingo
Caddo
Madill
MARSHALL
Durant
CHOCOTAW
Hugo
Garvin
Idabel
LOVE
Marietta
BRYAN
Red River
Map Showing Distribution of Trinity
Sandstone in Southeastern Oklahoma.

Plate VII.

(Pl. VII). It is bordered on the south by the Fredericksburg formation composed of limestones and shales which form a north-facing escarpment due to the fact that they are more resistant than the underlying sandstones of the Trinity.

Mr. Robert T. Hill separates the Trinity of Texas into three divisions. The lowest is referred to as the basal sand or the Travis Peak formation. It is composed of a series of sandstones and conglomerates several hundred feet in thickness. The middle division is a calcerous formation consisting of limestone interstratified with marly clays. The Poluxy sand forms the upper division and is composed principally of cross-bedded pack sand. The characteristics of these divisions continue into Oklahoma with the exception of the Glenn Rose formation which becomes dominantly a sandstone.

Mr. Pierce Larkin, who has done considerable work on the Trinity in Oklahoma, summarizes it as follows:[7]

"It consists principally of more or less unindurated sand. There also is much clay present which is usually quite arenaceous. None of these sand and clay members are continuous over large areas, but are usually cross-bedded and interstratified with lenticular beds, rarely more than 30 feet in thickness. The sand often grades into clay in very short distances, and it is rare indeed that one would be able to follow a ledge of either sand or clay for more than a mile without finding its character changed or entirely altered."

The heterogeneous composition of the Trinity shows constantly changing conditions of deposition and indicates that the formation was laid down near shore in shallow water, as the deposits laid down in deeper waters are subject to more gradual and less frequent changes. The presence of both salt and gypsum, abundance of lignite, silicified wood, and dinosaur remains are other facts which indicates the shallowness of water at the time the Trinity was laid down.

Localities.

In the study of the sands of this formation no attempt has been made to map in the beds or even to give their exact location. Among the localities that are accessible to transportation facilities the following have been studied: North of Marietta, near Durwood, at Russet, at Madill, north of Caddo, and south of Antlers.

7. Unpublished thesis in library of the State University of Oklahoma

Overbrook and Marietta.—The Trinity is exposed on the Gulf, Colorado, and Santa Fe Railroad between Overbrook and Marietta, where some thick beds of sandstone occur. On a small tributary of Little Hickory Creek one-fourth mile west of Greenville a sand bluff 25 feet high is exposed. The base is not shown (fig. 2). The top 15 feet of the bed is represented by sample G1, and the bottom 10 feet by sample G2, analyses of which are given below. The sand is of a brownish gray color and the grains are sub-angular and fairly uniform in size although rather small. The bed is covered with about 3 feet of surface soil which can be

Fig. 2.---Ledge of glass sand 4 miles south of Overbrook.

removed easily. This is an excellent location as it is only about 500 yards from the railroad and a spur could be run to the bed with very little grading.

The outcrop of the bed extends for considerable distance up and down the ravine and the beds show little or no cross-bedding. The dip is apparently very gentle to the southeast. The upper 15 feet contains such a large per cent of iron that it is unfit for anything but bottle glass. The grains are angular but too small to produce the best results. The 10 feet at the bottom is sufficiently pure for the manufacture of some of the better grades of glass. The quality of this sand may be improved, as a large per cent of the impurities can be removed by washing.

On the south bank of Little Hickory Creek about one-half mile east of the bluff just described and about 50 yards above the railroad crossing 25 feet of sand are exposed in a bluff. In appearance the sand here is the same as that in the bluff farther west, but as the base of this bluff is covered by sand which has fallen from the top, no fresh sample could be obtained. The sand in this bed is easily accessible and only about 3 feet of the loose surface soil need be removed.

Within the next mile to the south other bluffs of sand having the same appearance as that at Greenville are exposed. Furthermore, to the eastward are still other bluffs but these latter are not near any transportation facilities and were not closely inspected.

Analysis of samples of sand from near Greenville.

No.	Fe_2O_3	Al_2O_3	CaO	MgO	SiO_2	Organic matter.
G1	.42	1.88	.22	.04	96.988	.28
G2	.21	.73	.105	.032	98.878	.132

Size of grains of samples of sand from near Greenville.

No. \ Mesh.	40	60	80	100	200	Pan	Total.
G1	1.01	5.71	9.75	3.56	73.05	6.90	99.98
G2	.5	1.65	18.10	24.5	51.52	2.75	100.02

Durwood.—There is a large quantity of sand near the village of Durwood on the St. Louis and San Francisco Railroad, and the Chicago, Rock Island, and Pacific Railroad east of Ardmore. The surface of the land is rolling or even rough, and the soil sandy ,the whole being typical of a sand-hill country. There is a 17-foot bed of sand exposed on the south bank of a small creek about 1 mile

northeast of Durwood, analyses of which are given in sample G3 below. About 20 feet of impure sand and surface soil lies above this 17-foot bed. The exposure is easily accessible and the railroad is only one-half mile distant. A spur could therefore be built to this exposure at a very low cost.

Analysis of sample of sand from near Durwood.

No.	Fe_2O_3	Al_2O_3	CaO	MgO	SiO_2	Organic matter.
G3	.322	.75	.105	.025	98.593	.123
G3a	.133	.497	.105	.021	99.077	.085

Sample G3a is the same sand as G3 after being washed by immersion in water 1 hour.

Size of grains of sample of sand from near Durwood.

Mesh. / No.	40	60	80	100	200	Pan.	Total.
G3	1.5	6.61	25.31	23.3	40.79	2.5	100.01

A 20-foot bluff of sand is exposed in a small ravine about 2 miles southeast of Durwood. The upper 15 feet is too impure for glass sand. The 5 feet at the base is represented by sample G4, analysis of which is given below. In this are thin layers of coarse-grained sand containing a large per cent of iron and carbonaceous material. The base of the sand is not exposed. This bluff is not readily accessible on account of the rugged character of the country.

Analysis of sample of sand from 2 miles southeast of Durwood.

No.	Fe_2O_3	Al_2O_3	CaO	MgO	SiO_2	Organic matter.
G4	.112	468	.115	.052	99.123	.04

Size of grains of sample of sand from 2 miles southeast of Durwooa.

Mesh. / No.	40	60	80	100	200	Pan.	Total.
G4	2.68	57.4	27.58	7.03	5.34	.01	100.04

Russet.—A ledge of sand 15 feet thick, sample G5, is exposed in a ravine one-half mile south of Russet and one-fourth mile southeast of the Chicago, Rock Island, and Pacific Railroad. While the region as a whole is very rugged, a narrow ravine leads from the railroad to the deposit, rendering it accessible. It is underlaid by yellow clay and covered by three feet of surface soil.

Analysis of sample of sand from one-half mile south of Russet.

No.	Fe_2O_3	Al_2O_3	CaO	MgO	SiO_2	Organic matter.
G5	.126	.174	.07	.057	99.496	.022

Size of grains of samples of sand from one-half mile south of Russet.

No. \ Mesh.	40	60	80	100	200	Pan.	Total.
G5	.1	3.45	66.11	18.3	12.32	.25	99.98

The chemical and physical analyses show this to be a good grade of glass sand. The per cent of impurities is small and the grains are subangular and transparent.

Exposures similar to that near Russet are seen just below Randolph near the St. Louis and San Francisco Railroad. Another occurs near Teller, and still others are reported near Tishomingo, Milburn, and Filmore, on the Chicago, Rock Island, and Pacific Railroad.

Madill.—One-half mile northwest of the public square in Madill is a sand bluff 75 yards long and 25 feet high. It is capped by from five to ten feet of surface soil. The 10 feet of sand at the top of the exposure is reddish brown and contains too many impurities for glass. The next 10 feet is represented by sample G6. Crossbedding and irregular deposition are seen in the whole bluff. Portions of the 10 feet are made up of lenticular pockets of almost pure, white sand. Around these pockets are little seams of impure yellowish sandstone. At the base of the bluff occurs a greenish blue sandy clay. The bluff is only a short distance from either branch of the St. Louis and San Francisco Railroad and can be reached easily. From this bluff the sand extends to the south and underlies almost the entire town of Madill. The following analysis shows the character of the sand.

Analysis of sample of sand from near Madill.

No.	Fe_2O_3	Al_2O_3	CaO	MgO	SiO_2	Organic matter.
G6	.154	.636	.1	.061	98.89	.08

Size of grains of sample of sand from near Madill.

No. \ Mesh.	40	60	80	100	200	Pan.	Total.
G6	.95	1.85	27.35	27.45	40.29	2.12	100.01

Caddo to Atoka.—Along the Missouri, Kansas, and

Texas Railroad from a point 4 miles north of Caddo north nearly to Atoka are several good exposures of sand in the railroad cuts. The following section of Trinity between Atoka and Caddo is given by Mr. Larkin.[8].

Section of Trinity from Caddo to Atoka.

		Feet.
No. 1.	yellow clay with local lenses of conglomerate containing large waterworn boulders	10
No. 2.	grayish yellow, sandy clay which grades downward through many thin lentils of course, waterworn, and angular gravels	30
No. 3.	fine conglomerate in beds of gray sandy clay	30
No. 4.	yellow and brown pack sand	10
No. 5.	yellow, sandy clay	10
No. 6.	gray, sandy clay with yellow streaks	40
No. 7.	hiatus, bottom land	80
No. 8.	yellow clay streaked with red and containing lenses of gray indurated sandstone	40
No. 9.	grayish yellow clay, sandy at the base	20
No. 10.	reddish yellow sand in matrix of clay	20
No. 11.	hiatus, valley of Davis and Boggy Creek	80
No. 12.	grayish white sand	20
No. 13.	blue, arenaceous clay streaked with yellow	10
No. 14	reddish, yellow sand cross bedded	12
No. 15.	grayish, blue sand with clay matrix	12
No. 16.	green colored arenaceous clay	22
No. 17.	pack sand reddish brown with iron stone concretions at the base	8
No. 18.	grayish yellow clay red in places and containing occasional lenses of sand	32
No. 19.	blue arenaceous clay with lenses of white sand	10
No. 20.	yellow pack sand	10
No. 21.	yellow clay changing into white sand, much cross-bedded, then into yellow sand in matrix of fine yellow clay in one of which was found the dinosaurian coracoid	40

8. Op. cit.

No. 22.	yellow clay arenaceous in places....	12
No. 23.	arenaceous clay grayish yellow clay iron stone concretions present with it	15
No. 24.	reddish, gray sand with unidentified species of Gryphaea and Ostrea......	12
No. 25.	grayish yellow sand in matrix of clay very argillaceous in places..........	32
No. 26.	yellow clay streaked with blue sand in places	6
No. 27.	yellow pack sand cross bedded.......	10
	Total	633

The Trinity in this region is characteristically a composite of sand and clay. Usually there are no sharp boundaries between the sand and clay beds, the gradation being gradual from one to the other. In places, however, irregular changes take place, both vertically and horizontally. At other places the sand gives way horizontally to the clay which continues for some distance and then suddenly becomes again predominantly sand.

In the long cut 1½ miles north of Tushka on the Missouri, Kansas, and Texas Railroad, 5 to 20 feet of sand is exposed. Some of this is pure white sand, but it occurs in small lenticular pockets and is not in sufficient quantity to be worked.

One-half mile south of Tushka there is another cut similar to the above. White sand is also found here in small pockets. The deposit on the whole is cross-bedded, lenticular, and contains a large per cent of impurities.

In the big cut 2½ miles north of Caney as much as 30 feet of sand is exposed, and the irregular character seen in the other cuts is in evidence at this place also. From one of the lenticular pockets sample G7 was taken. This pocket is the most prominent exposure seen between Atoka and Caddo and is about 50 feet long and 10 feet thick.

Analysis of sand from railroad cut 2 1-2 miles north of Caney.

No.	Fe_2O_3	Al_2O_3	CaO	MgO	SiO_2	Organic matter
G7	.098	.152	.04	.056	99.507	.117

Size of grains of sand from railroad cut 2 1-2 miles north of Caney.

No. \ Mesh.	40	60	80	100	200	Pan.	Total.
G7	2.05	2.47	24.11	25.35	42.75	3.25	99.98

The grains are subangular and transparent.

Goodland to Antlers.—A few pockets of white sand were seen in the Trinity along the St. Louis and San Francisco Railroad between Antlers and Goodland but such evidence as could be obtained indicates that the purer grade of sand does not occur in sufficient quantity. Boring might reveal a considerable quantity of good sand but it would doubtless be in pockets and hence too uncertain in quantity to warrant being quarried at present.

Summary.

From the above discussion of the several localities of the Trinity it will be seen that in several places commercial quantities of good sand occur. The deposits at Greenville, northeast of Durwood, and at Madill are readily accessible. It should be noted, however, that the beds of sand extend east and west along the strike from the exposures described in each case, the details of the several localities being given to show the general character and manner of occurrence of the glass sand in the Trinity as a whole. Other localities might be cited in which the deposits would compare favorably with those described.

Silo Formation.

Glass sand has been reported in the Silo formation which outcrops in Marshall, Bryan, and Choctaw counties, south of the Washita formation, but a study of this formation fails to substantiate this report. The Silo is composed of sand and shales very much like those of the Trinity, but are more regular.

A 20-foot bed of sandstone runs east and west, north of *Durant*. It outcrops on the bank of a creek about one-half mile northeast of the Normal School building. The bed is capped with 3 feet of surface soil. Underneath this surface soil 2 feet of coarse-grained sand occurs. The next 8 feet is represented by sample H1, the analysis of which is given below and shows the sand to be suitable for the poorest grades of bottles. The lowest 12 feet runs high in iron and cannot be used for any grade of glass. South of Durant only an occasional thin bed of sand is seen. These contain too large a per cent of impurities to be classified as glass sand.

Analysis of sample of sand from Durant.

No.	Fe_2O_3	Al_2O_3	CaO	MgO	SiO_2	Organic matter.
H1	.868	1.222	.105	.021	97.192	.516

Size of grains of sample of sand from Durant.

Mesh. / No.	40	60	80	100	200	Pan.	Total.
H1	1.25	1.3	6.85	17.45	71.47	1.65	99.97

TAHLEQUAH AREA.

General features.—The third area in which glass sand occurs in quantity in Oklahoma is in the northeastern part of the State in the northeast corner of T. 17 N., R. 22 E., 5 miles northeast of Tahlequah along Illinois River (Pl. VIII). The surface of this region is very rugged. The Illinois River and its tributaries have cut deep garges through the hard limestone and cherts which occupy the surface, into the softer rocks beneath. The meanderings of the Illinois River add another obstacle in the way of the development of these deposits.

The region has been studied and mapped in detail by Taff[9]. The following formations are described:

The *Burgen sandstone*, consisting of massive brown sandstone 50 to 100 feet thick lies at the base of the series. It is this formation that carries the glass sand. Above the Burgen sandstone occurs the *Tyner formation* 60 to 100 feet thick, which is composed of brown sandstone and thin siliceous limestone and chert above; and brown, thin-bedded and flaggy sandstone and greenish shale below. Above the Tyner formation and lying uncomformably upon it occurs the *Chattanooga formation* 0 to 45 feet thick which consists of a black shale with a sandstone at the base. The Chattanooga is succeeded by the *Boone formation* 100 to 300 feet thick consisting of chert and cherty limestone. The Boone formation occupies the surface over wide areas in the upland in the vicinity of Tahlequah and on both sides of the Illinois River.

Occurrence and character of sand.—Mr. Taff in the Tahlequah folio, page 2, describes the Burgen sandstone, which carries the glass sand, as follows:

"The Burgen sandstone is a massive, moderately fine-grained light brown rock. The beds are thick and planes of stratification are usually indistinct. The rock consists of nearly pure siliceous sand of rounded grains, with a matrix scarcely sufficient to cement them together.

9. Taff, Joseph A., Tahlequah folio (No. 123), Geol. Altas U. S., U. S. Geol. Survey, 1905.

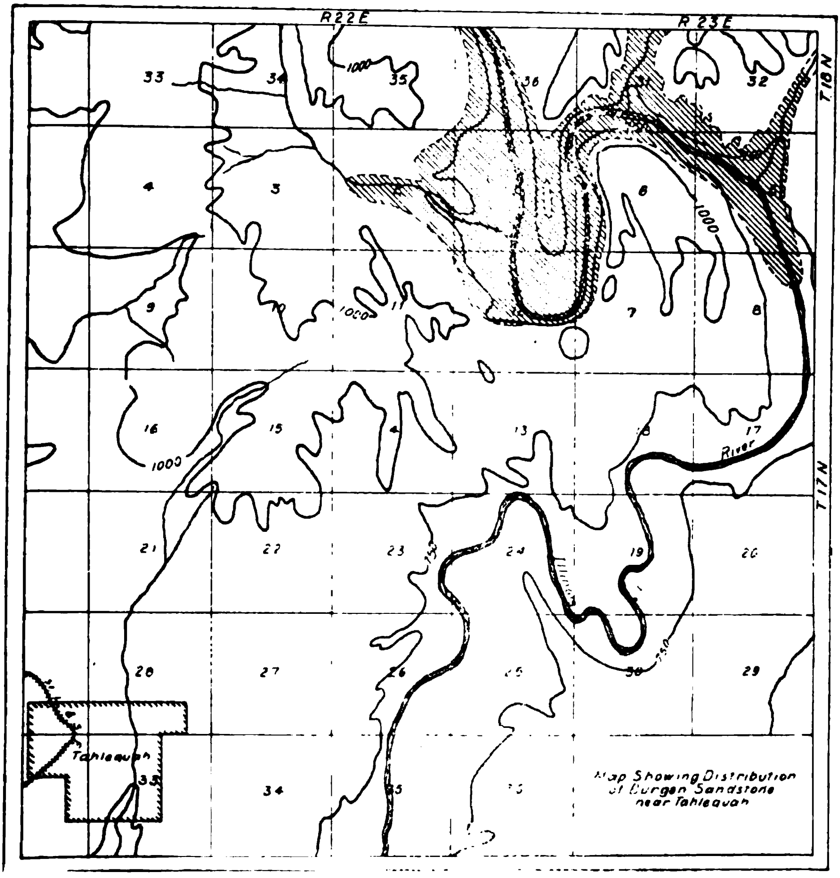

R22E
R23E
T.18N
T.17N
Tahlequah
River
1000
Map Showing Distribution of Burgen Sandstone near Tahlequah

Plate VIII.

"In natural exposure the rock breaks readily under the stroke of the hammer, crumbling into loose sand. The formation varies in thickness from a thin stratum to beds aggregating more than 100 feet. It is exposed in the Tahlequah quadrangle in but a single area, on the Illinois River northeast of Tahlequah where it rises in bluffs to a height of nearly 100 feet, and the base is not exposed. The full thickness, therefore, is certainly not less than 100 feet."

The Burgen sandstone is correlated with the St. Peters sandstone which is one of the principal glass sand bearing formations in Minnesota, Wisconsin, Iowa, Illinois, and Missouri.

The workable sand of the Burgen sandstone in this area occurs in a 50-foot bluff which is exposed for one-fourth mile along the north bank of the Illinois River in the southwest corner of sec. 31, T. 18 N., R. 23 E. (fig. 3). Sample I1 was taken from different places in the bluff and is a fair representative of the sand.

Fig. 3.---Ledge of sand in the Burgen sandstone 7 miles northeast of Tahlequah.

Analysis of sample of sand from the Burgen sandstone 5 miles northeast of Tahlequah.

No.	Fe_2O_3	Al_2O_3	CaO	MgO	SiO_2	Organic matter.
I1	.14	.32	.18	Trace	99.22	.0028

Size of grains of sample of sand from the Burgen sandstone 5 miles northeast of Tahlequah.

Mesh. / No.	40	60	80	100	200	Pan.	Total
11	3.85	22.14	40.92	18.75	13.25	1.07	99.98

While this sand shows by its analysis that it is high grade, its remoteness from railroad and the high cost of constructing a spur to the deposit, together with the fact that a heavy capping of limestone occurs above the sand renders it improbable that development will take place in the near future. However, it is reported that construction of a railroad through this region is being contemplated. If the road should be constructed and pass close to the deposits, their value would be greatly enhanced.

AVAILABLE LIMESTONE.

Although frequent reference has been made to limestone beds in the several regions and especially in the Arbuckle Mountain region, a brief statement as to available limestone at this point in the discussion will add clearness.

Associated with the sand beds of the Simpson formation are numerous beds of limetsones many of which are relatively pure but some are highly siliceous grading vertically into sandstone or shale. The pure limestone beds are easily accessible and are thick enough to afford cheap and abundant supply of lime. Furthermore, the Viola and Arbuckle limestones are always well exposed in close proximity to the sand deposits. It should be noted, however, that, as shown by the analyses, many of the beds of sand in the Simpson formation already contain approximately the requisite amount of lime. The percentage of lime in these beds seems to be very constant for considerable distances along the strike. This condition will then obviate the necessity of adding lime to the batch.

Overlying the Trinity sand in the southeastern Oklahoma is the Goodland limestone, which affords an adequate supply of lime in that region.

In the vicinity of Tahlequah the Pitkin limestone and various beds in the underlying Fayetteville formation are widely exposed, usually outcropping in bluffs. At the base of the Boone formation also is a thick bed of pure limestone with a maximum thickness of about 30 feet. The upper part of this same formation is composed of about 35 to 50 feet of relatively pure limestone beds.

Throughout northeastern Oklahoma in general where an abundant supply of cheap gas is available, are numerous beds of good limestone, ranging up to 100 feet in thickness, well exposed and easily accessible to transportation facilities.

PRESENT CONDITIONS OF GLASS INDUSTRY IN OKLAHOMA.

Glass plants.—The glass sand industry is in its infancy in Oklahoma. At present there are six plants in operation, namely: The Tulsa Glass Company, at Tulsa; The Neodesha Bottle and Glass Company, at Tulsa; The Graham Glass Company, at Okmulgee; Bakers Brothers' Window Works, at Okmulgee; and two other small plants, one at Bartlesville and the other at Avant.

The Tulsa Glass Company produces lamp chimneys, lantern globes, gas globes, soda fountain tumblers, and one to five gallon water bottles. They employ 150 people with an annual pay roll of $75,000. Their capacity is 1 2-3 tons a day.

The Neodesha Bottle and Glass Company produces bottles and globes of all kinds and sizes. They employ 200 men with an annual pay roll of $240,000. The daily capacity of the plant in finished products is 21 tons.

The plant of the Graham Glass Company at Okmulgee is devoted to the manufacture of beer and soda bottles in light green glass by special bottle machines. They employ 80 men.

The Baker Brothers' plant at Okmulgee manufactures window glass and the small plant at Bartlesville is devoted to the manufacture of bottles and that at Avant to the manufacture of chimneys.

The sand used in these plants is obtained from the Pacific and Crystal City fields near St. Louis, Missouri. A sample of the sand used by the Neodesha Bottle and Glass Company which is obtained from the Cavern Rock Company at St. Louis, gives the following results:

Analysis of sample of sand from Cavern Rock Company.

No.	Fe_2O_3	Al_2O_3	CaO	MgO	SiO_2	Organic matter
J1	.112	.938	.145	.027	98.645	.02

Size of grains of sample of sand from Cavern Rock Company.

No. \ Mesh.	40	60	80	100	200	Pan.	Total.
B4	.95	3.56	20.12	31.1	41.62	2.64	99.99
J1	10.44	48.71	29.16	7.26	4.23	.17	99.97

The grains are irregular in size and only the smaller ones are subangular. The larger grains are rounded.

Conclusions.—A study of the analyses of the samples of sand taken from the glass sand deposits in Oklahoma shows that Oklahoma contains inexhaustible quantities of sand which is a better grade than that obtained from the Missouri fields by the Oklahoma plants.

In addition to the better quality of sand, cheaper freight rates can be obtained. M. W. Conway, superintendent of the Tulsa Glass Company, was offered a rate of five cents a hundred from the Roff sand deposits in the Arbuckle Mountains to Tulsa. At the present time the rate on the sand from St. Louis to Tulsa is 12 cents a hundred. Since the glass sand deposits of Oklahoma are accessible and are of as good quality and much nearer to the glass plants in Kansas and Oklahoma than the glass sand deposits in Missouri, there is little reason why Kansas and Oklahoma should not be supplied with Oklahoma sand.

Brannin

OKLAHOMA GEOLOGICAL SURVEY

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BULLETIN NO. 11

THE GYPSUM AND SALT OF OKLAHOMA

By L. C. SNIDER

NORMAN
JULY, 1913

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CONTENTS

ILLUSTRATIONS

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The gypsum companies, with two exceptions, permitted the writer to visit their mills and rendered much assistance in the preparation of the report. One of the two companies whose rules do not allow their mills to be visited gave by correspondence all the information desired concerning their mills and products.

The United States Geological Survey has permitted the reproduction of figures 2, 3, 4, 29, 30, 41, 42, 43, 45, 48, 49, 58, 60, 63, 64, and 65. Half-tones, etchings, drawings, or photographs were furnished by the J. B. Ehrsam & Sons Machinery Company, Enterprise, Kansas, for figures 8, 9, 10, 11, 12, 13, 19, 20, and 21; by the F. D. Cumner & Son Company, Cleveland, Ohio, for figures 14, 15, 16, and 17; by the United States Gypsum Company, Chicago, Illinois, for figures 22, 26, and 28; and by the Oklahoma Gypsum Company, Homestead, Oklahoma, for figure 25.

CHAPTER I.

GENERAL CONSIDERATION OF GYPSUM.

CHEMICAL AND PHYSICAL PROPERTIES.

Composition.—Gypsum is the hydrous calcium sulphate, that is, the sulphate of lime with water of crystallization. Its composition is expressed by the formula $CaSO_4.2H_2O$. It contains when pure 32.6 per cent of lime (CaO), 46.5 per cent of sulphur trioxide (SO_3), and 20.9 per cent of water. The anhydrous sulphate, anhydrite, has the formula $CaSO_4$ and is often associated with gypsum, either in considerable masses or disseminated through the gypsum. Beds of gypsum practically always contain appreciable quantities of other impurities the more common of which are iron and aluminum oxides, calcium and magnesium carbonates, clay, and sodium chloride or common salt.

Hardness and specific gravity.—Gypsum is a very soft mineral, the crystallized form having a hardness of 2 in the Mohs' scale. It is easily scratched with the thumb nail. The specific gravity of pure gypsum is 2.32, but that of the gypsum found in nature varies from 2.30 to 2.40. Its specific gravity in comparison with that of calcined gypsum, limestone, lime mortar, and Portland cement is shown in the following table.[1]

	Specific Gravity
Limestone	2.46 to 2.84
Quicklime	2.30 to 3.18
Lime mortar	1.64 to 1.86
Gypsum	2.30 to 2.40
Calcined gypsum	1.81
Portland cement	2.72 to 3.05

Color.—Gypsum is clear and transparent in the pure crystallized form, selenite, but the presence of impurities gives various shades and tints of pink, red, blue, green, and even black. Beautiful effects are given in some of the Oklahoma

[1]Wilder, Frank A., Geology of Webster County: Iowa Geol. Survey, vol. 12, 1901, p. 139.

selenite by the inclusion of cloudy masses of red iron oxide or hydroxide, and of a black substance, probably organic matter, which gives a wavy effect. Green is very common in the selenite lakes and in the clays and sandstones occurring below the main gypsum ledges. This color is probably due to iron, part of which is in the ferrous condition. The fine-grained or rock gypsum is predominantly white but shades of red are of common occurrence. Dark veins or spots may be due to organic matter.

Crystallization.—Gypsum (selenite) crystallizes in the monoclinic system, the common forms of the crystals being plates or prisms with pyramidal terminations. The cleavage is almost perfect, parallel to the 010 face (face b in figure 1) and selenite is readily split in this direction into very thin sheets. This splitting into thin sheets often causes selenite to be mistaken for mica, but the thin flakes of selenite are brittle and not elastic as are the mica flakes. The cleavage is also usually good parallel to the face *n* shown in figure 1. As a result of the two cleavages selenite may often be split into rhombohedrons. Twinning is common on the orthopinacoidal face and the edges of the twinned crystals are sometimes rounded. The common forms of gypsum crystals are shown in figure 1.

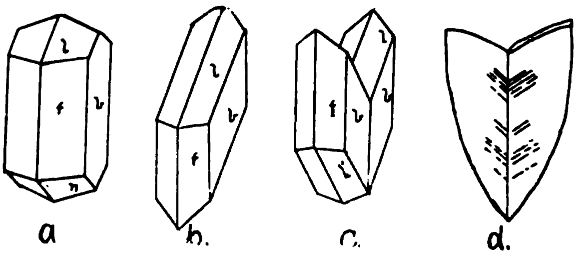

Fig. 1.—Forms of gypsum crystals.

a. Form of gypsum crystal.
b. Common form of gypsum crystal.
c. Twinned gypsum crystal.
d. Twinned gypsum crystal with edges rounded.

Solubility.—Gypsum is only slightly soluble in water as is shown by the following table by Marignac:[2]

[2]Annales de Chimie, Paris, 5th series, vol. 1, pp. 274 to 281. Quoted and verified by G. P. Grimsley, Univ. Geol. Survey of Kans., vol. 5, p. 86.

Solubility of Gypsum, by Marignac.

Temperature	One part of gypsum dissolves in—	One part anhydrous sulphate lime dissolves in—
At 32F. =0C.	415 parts of water	525 parts of water
At 65.5F. =18C.	386 " " "	488 " " "
At 75.2F. =24C.	378 " " "	479 " " "
At 89.6F. =32C.	371 " " "	470 " " "
At 100.4F.=38C.	368 " " "	466 " " "
At 105.8F.=41C.	370 " " "	468 " " "
At 127.4F.=53C.	375 " " "	474 " " "
At 161.6F.=72C.	391 " " "	495 " " "
At 186.8F.=86C.	417 " " "	528 " " "
At 212F =100C.	452 " " "	572 " " "

Although gypsum is so slightly soluble in pure water, the effects of ground water acting upon gypsum deposits through long periods of time are very striking. Caves and sink holes abound in the gypsum region of Oklahoma and ledges are often absent from the outcrops for considerable distances on account of their being dissolved out. The more coarsely crystalline gypsum seems to be more strongly acted upon than the dense fine grained varieties, probably because the cleavage planes and the surfaces between the different crystals permit the water to percolate through the crystalline gypsum more easily than it can through the dense varieties. The effect is to increase greatly the surface of gypsum exposed to the water and to increase correspondingly the solvent action. There is no reason to suppose that the crystalline gypsum is actually more soluble than the amorphous form.

VARIETIES AND OCCURRENCE OF GYPSUM.

Gypsum occurs in nature in several different forms to some of which reference has already been made. The forms usually encountered, are rock or amorphous gypsum, selenite, satin spar, and gypsite or earth gypsum. Anhydrite (calcium sulphate without water of crystallization) is closely related to gypsum and occurs intimately associated with it, so it is considered in this connection.

Rock gypsum.—Both the amorphous or non-crystalline forms and the crystalline form in which the crystals are too small to be observed by the unaided eye are commonly called rock gypsum. The term is sometimes used to include all oc-

currences of gypsum in heavy ledges, although the ledges may be composed of crystals of selenite of considerable size. In this report the fine-grained form is called rock gypsum while the form in which the individual crystals are large enough to be easily distinguished is called selenite or selenitic gypsum. There is, of course, no sharp line between these types but the distinction is convenient in discussing the deposits in Oklahoma.

Pure rock gypsum is white but, as it occurs in nature, is often colored by the presence of foreign material. Iron is probably the most common coloring agent and produces the pink and red shades and probably the green. Beds of gypsum are often

Fig. 2.—Massive gypsum showing banded structure (U. S. Geol. Survey).

irregularly mottled or banded (fig. 2) with darker material, which is probably due to organic matter since the color is usually destroyed by calcining.

Rock gypsum usually occurs in massive beds of considerable areal extent. In Oklahoma beds up to 60 feet in thickness are known and this thickness is exceeded in other regions.

Selenite is the crystalline form of gypsum. The general form of the crystals is shown in figure 1, and where the individual crystals occur separately they usually take on the shapes shown in the figure. A number of such crystals are shown in figure 3. When the crystals grow in masses the relative sizes of the faces vary greatly and the individuals are flat

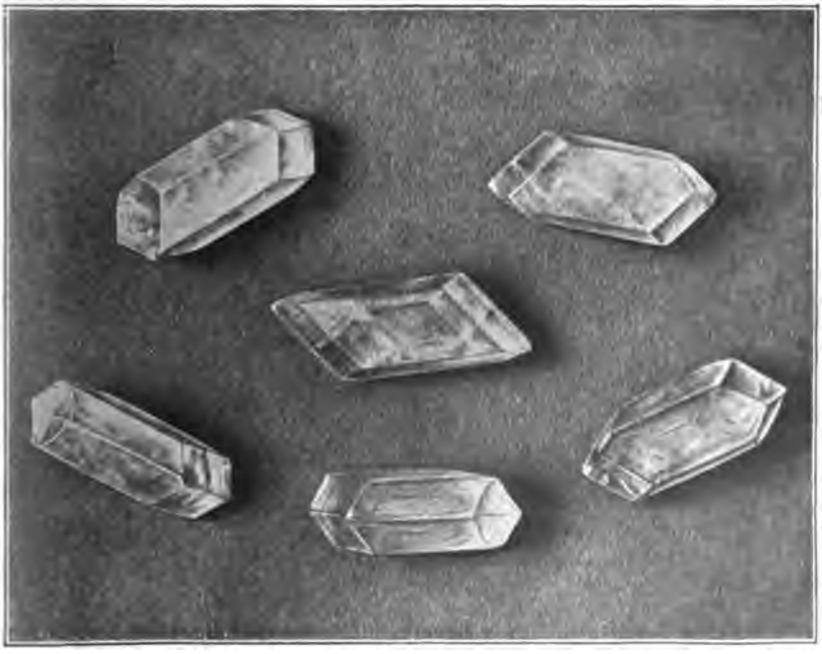

Fig. 3.—Selenite crystals (U. S. Geol. Survey).

or tabular and very thin. This method of crystal growth, with the perfect cleavage, causes a large piece of selenite to split easily into thin sheets. The sheets are slightly flexible but are not elastic. Pure selenite is transparent. The foliation and the transparency often cause selenite to be mistaken for mica.

The sheets of mica, however, are elastic, *i. e.*, when they are bent they will return to their original shape when the pressure is released. The cleavage, slight flexibility, and transparency of selinte are shown in figure 4.

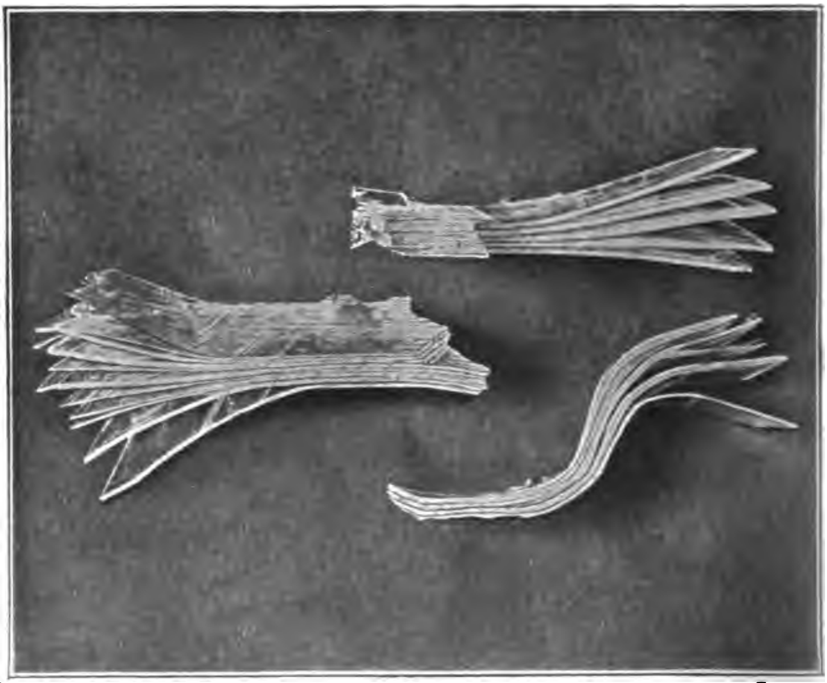

Fig. 4.—Selenite which has been split and bent to show cleavage and slight flexibility (U. S. Geol. Survey).

Selenite usually occurs in bands or veins in the clays below the massive gypsum ledges or, in some regions, unassociated with large gypsum deposits. Locally in Oklahoma crystals of the general shape of those shown in figure 3, are loosely aggregated and the interstices filled with clay. Some of the massive beds are composed of selenite crystals of as much as 3 or 4 inches in their dimensions. The weathered surfaces of such beds give a sort of mosaic effect due to the irregular outlines and different orientations of the crystals. This is rather poorly shown in figure 32 in chapter V. Some very large crystals or crystal masses in which the crystals are similarly oriented have been found in Oklahoma. One found in Dewey County and now on exhibition in the Mineral Building at the Oklahoma

State Fair is about 4 feet long, over 1 foot wide, and 6 inches thick.

Satin spar is crystalline gypsum in which the crystals are needle-like or fibrous. It occurs as veins in shales or other rocks associated with massive gypsum deposits. The veins are seldom over 3 or 4 inches thick. The crystals or fibers extend perpendicular to the length of the vein. In many veins there is a very thin sheet through the middle in which the fibers are parallel to the length of the vein with the fibers of the portions on either side perpendicular to this layer. These veins are deposited by the evaporation or gypsiferous water from the surface of the slopes below the gypsum beds, and usually extend from the surface only a short distance back into the clay. The veins may have any direction in relation to the bedding planes or joints although veins usually occur along both of these when they are well developed.

A typical occurrence of thin bands of satin spar in the clays below the heavy gypsum ledges is shown in figure 5. The fibrous nature of the material is faintly shown in some of the thicker bands. The same phenomena are shown on a larger scale in figure 48 in chapter V. Satin spar does not occur in

Fig. 5.—Veins of satin spar in clay below heavy gypsum ledge, 1 mile east of Indianapolis, Custer County.

sufficient quantities to be commercially valuable by itself, though small quantities of it may be worked with other forms of gypsum.

Gypsite, earth or dirt gypsum, is an impure form of gypsum containing variable quantities of clay and sand. The percentage of calcium sulphate varies from about 50 to about 75 per cent. Clay and fine sand together make up the most of the rest of the material. The clay may carry some iron and more or less organic matter. Gypsite is soft and incoherent and it is easily worked with scrapers or drag scoops. In color gypsite is usually gray, mottled or speckled with white, but where the clay contains much iron the material may be pink or even red. Gypsite occurs generally along the valleys of the small streams or in flats below the level of the gypsum ledges. At some of the deposits in Kansas and in southwestern Oklahoma, the gypsum occurs below rather than above the gypsite deposits. The thickness of the deposits differs greatly even in the same bed. As a general rule they are not over 2 feet thick at the foot of the hills and reach 10 or 12 feet near the stream if the bed is in a valley. The origin of gypsite has been cause of considerable discussion. The statement which applies best to the Oklahoma deposits is that of Grimsley[3] which is given in full.

Origin of the Secondary Gypsum Deposits.

"The deposits of earthy gypsum in the central part of the state were formed at a much later time than the rock deposits we have been describing. They occur in low, swampy ground and strong springs of gypsum water occur in nearly all of them.

"At the same level or 10 to 20 feet below the earth is a stratum of solid gypsum, while near most of these deposits no gypsum is found above. Near the bottom of the Rhodes deposit Dr. S. Z. Sharp found recent shells of general *Planorbis* and *Physa*, and an Indian spear-head was also found. Similar shells were found by the writer, in the Longford earth near the bottom of the deposit. In the earth south of Dillon bones and shell were found.

"Gypsum in a form resembling satin spar and in an earthy form is deposited at the present time in dry weather to the extent of a half inch in a few days by evaporation of running water along channels near these places. Where the gypsum

[3]Grimsley, G. P., Gypsum and Gypsum Cement Plasters: Univ. Geol. Survey of Kans., vol. 5, 1899, pp. 81-83.

water of the springs in these deposits is evaporated there remains a crust of gray earthy gypsum resembling very closely the gypsum earth. Sand, clay and lime in small amounts occur in the deposit mingled with some organic material, as shown in the following analyses of rock and earth gypsum, by Professor E. H. S. Bailey:

	Gypsum Rock in Hope Shaft	Gypsum Earth at Dillon, Agatite Deposit
Silica and insoluble residue	0.34	6.49
Iron and aluminum oxides	0.16	1.04
Calcium sulphate	76.98	65.97
Calcium carbonate	1.68	6.96
Magnesium carbonate	1.30	0.27
Water	19.63	18.56
	100.09	99.29

"In all the analyses made the amounts of silica, alumina and lime carbonate in the earth deposits are higher than in the rock, which would be expected in a secondary deposit in a swamp. The amount of sulphate of lime is lower, so that the earth deposits are not as pure as the rock strata. The impurity of the earth makes it set more slowly, and so makes the material more favorably adapted to wall-plaster manufacture.

"The microscopical crystals of gypsum in this earth are angular and many of them perfect. No masses of gypsum rock are ever found in the earth, and no fragments of other stone or sand in any amount. The material is quite uniform in size and chemical composition through the whole deposit. If the material was washed from gypsum rock of higher levels, as some have maintained, some fragments of gypsum and other rock would certainly be found in some of these deposits.

Spring Theory of Origin.

"The gypsum earth, then, must have been deposited in these places from solution. If from solution in surface streams, considerable sand and silt would be carried in and the chemical composition would vary in different parts of the mass. Further, as in nearly all the areas, no gypsum is over the earth, so that the streams would have to bring the material from long dis-

tances. Some sand, clay, lime carbonate, and organic material are shown by chemical analyses and by the microscope, and these may be due to surface agencies. The water circulating through or near the underlying gypsum rock dissolved a portion of the rock and carried it upward in the springs to the surface of the swamp where the mineral was precipitated through evaporation aided by the action of organic matter of decaying vegetation.

"A crust of gypsum would thus be formed and would increase in thickness until all the underlying rock was removed. Now, in some of these deposits borings detect no gypsum below the deposits, but it is found in wells outside at a level below the earth. In such places probably all the gypsum rock adjacent to the gypsum earth area has been removed by solution. Again by building up the swamp floor to a certain height the rise of gypsum water springs may have been so checked as to hinder the earth formation. Whatever the cause, the gypsum earth deposit is not now forming over the entire area in any appreciable amount.

"The uneven thickness of the deposits, some varying from 3 to 8 feet within the main part of the deposit, shows that the conditions were more favorable at certain points than others. Probably these thicker portions were nearer the outlet of stronger springs.

"The deposits were formed in a comparatively short period of time. The presence of modern fresh water shells shows that the deposit is a recent one, formed long after the rock gypsum of the same region."

The discussion applies to the Oklahoma deposits except in a few features. Very few if any of the beds in this state are swampy but all lie on low, level land, or in valleys between the gypsum hills. The deposits of the first line of hills along Cimarron River are below the heavy gypsum ledges and probably contain an admixture of material washed down the slopes. The bulk of the gypsite in these beds, however, is almost certainly formed by crytallization from water solution. In the case of the large gypsite beds in Custer, Harmon, Jackson, and Caddo counties the gypsum is below the gypsite. Shells similar to those mentioned as occurring in some of the Kansas deposits were observed in only one bed in Oklahoma (east of India-

napolis), but careful search might bring them to light in other deposits. Strong springs break out a short distance south of this deposit.

Gypsite is important in the plaster industry of the State. Two mills use gypsite alone and several others use gypsite and rock gypsum together. Gypsite is used for plaster in Kansas, Texas, and Wyoming.

Anhydrite.—Strictly speaking, anhydrite is a distinct mineral and cannot be considered as a form of gypsum. However, it is so closely related to gypsum and is so closely associated with it in nature that it is considered in this connection. Anhydrite is calcium sulphate, $CaSO_4$. It may be considered as gypsum without water of crystallization. It is usually a colorless or white mineral but may be tinted red, blue, or gray by impurities. Its hardness is 3 to 3.5, and its specific gravity, 2.95. It crystallizes in the orthorhombic system and has a cleavage resembling that of gypsum. Gypsum and anhydrite are easily distinguishable in the field by the difference in hardness, since gypsum is easily scratched by the fingernail while anhydrite cannot be.

Anhydrite occurs in Oklahoma in beds associated with gypsum. The most prominent occurrence is in northern Blaine and in Major counties, where the anhydrite occurs as a bed 3 to 5 feet thick in the Medicine Lodge gypsum. (See figures 45 and 46.) Locally the anhydrite is not in a continuous bed but occurs as bowlders or lenses. The lowest ledge of the Greer gypsum in the southwestern part of the State seems to contain considerable anhydrite disseminated through the gypsum.

The weathering of anhydrite is very distinct from that of selenite or of fine-grained gypsum. On slopes gypsum weathers to a soft incoherent powder which covers the fresh gypsum to considerable depth. Anhydrite on the other hand remains hard and white. The weathering of the large blocks which have their surfaces level with the ground usually produces a concave surface with very sharp minor irregularities which are apparently due to washing by rain. This weathering is well shown in figure 6.

Fig. 6.—Weathered surface of anhydrite blocks near Southard.

THEORIES OF ORIGIN OF GYPSUM.

Several theories have been advanced to account for the origin of gypsum deposits all of which are probably applicable to different deposits. The principal theories will be briefly reveiewed here.

Formation of gypsum by the action of sulphuric acid or scluable sulphates on limestone.—If sulphuric acid acts on limestone or any other form of calcium carbonate, gypsum is produced. The reaction stated in its simple form is $H_2SO_4+CaCO_3=CaSO_4+H_2O+CO_2$. The sulphuric acid may be derived from the oxidation of hydrogen sulphide (H_2S) of sulphur springs or of volcanic emanations, or by the oxidation of pyrite or iron sulphide (FeS_2).

Gypsum is formed directly by some thermal springs as in Iceland by the action of the sulphurous waters on volcanic tufa. Small gypsum deposits and crystals are found around amaroles of volcanoes. The formation of the gypsum deposits of New

York was attributed by Dana to the alteration of limestone by water from sulphur springs which occur in the gypsum region. Shale layers pass through the gypsum and the gypsum grades into the overlying water lime beds. These deposits are thought by others to have been deposited by evaporation of sea water. The deposits of Nova Scotia and New Brunswick have been attributed to the same source. Concerning these deposits Jennison[4] says:

"Dawson, in discussing the different theories and referring particularly to the deposits of Nova Scotia and New Brunswick, says:

" 'I think it is not improbable that there are instances of all or of most of these modes in the gypsiferous rocks of Nova Scotia. But for the occurrences of the mineral in so thick and extensive beds, interstratified with marl and limestone, there appears to me to be but one satisfactory theory—that of the conversion of submarine beds of calcareous matter into sulphate of lime, by free sulphuric acid poured into the sea by springs or streams, issuing from volcanic rocks. Modern volcanoes frequently give forth water containing sulphurous and sulphuric acids.' Water of this kind would have a greater specific gracity than sea water, and, therefore, flow along the bottom of the sea, and if it came in contact with beds of calcareous matter, the above action would take place and the formation of gypsum would be the result.

"Quite in accordance with this view the gypsum deposits of Nova Scotia and New Brunswick are found, without exception, associated with marine limestone. In some cases they are so closely associated that it is difficult to draw any line of demarcation; one graduating with diminishing or increasing prominence over the other.

"In the gypsum deposits at Tom river, Richmond county, N. S., a vein of limestone about 2 feet wide may be seen in an exposure of gypsum, 20 to 30 feet high. It cuts it transversely and has very distinct walls. * * *

"In the great gypsiferous belt at Cheticamp, Inverness county, N. S., a distinct belt of limestone, having a thickness

[4]Jennison, Wm. F., Gypsum of the Maritime Provinces: Canada Dept. of Mines, Mines Branch, No. 84, 1911, pp. 28-29.

averaging about 100 feet, may be seen, vertical, and separating a bed of snow-white massive gypsum from a bed of the greyish-white, selenitic variety.

"Everywhere, in the gypsiferous field, there is evidence that at one time there existed very extensive deposits of marine limestone. These deposits are often in close contact with what are now our metamorphic hills and mountain ranges. The volcanic action which created these metamorphic hills was not extinct when the marine limestone beds were growing and no doubt afforded the greater supply of sulphuric acid which converted the limestone into gypsum. If this supply was not sufficient, or if the conversion was not complete before the volcanoes became extinct, it is possible that the supply may have been supplemented from other sources, and the action completed.

"The sulphureted hydrogen springs, found in different localities, the iron pyrites, pyrrhotite, chalcopyrite, and arsenopyrite deposits, are all sources of sulphuric acid, and, found in the older rocks in the near vicinity, are quite sufficient to supply the deficiency if it were required. It is, therefore, quite evident that there was, from the many sources, an abundance of sulphur in the field during the Carboniferous age."

Jennison regards the "blow holes" which are of common occurrence in the gypsum and which differ in character from the ordinary sink holes, as vents through which the gases formed by the alteration of limestone to gypsum escaped; and also regards this as additional proof of the origin by alteration of limestone.

Sherwin[6] suggests that the massive deposits in Oklahoma and Kansas were formed by the action of water from sulphur springs on calcium carbonate in solution or on the limestone after it was deposited. He does not, however, account for the presence of sulphur springs sufficient to form such vast deposits.

The decomposition of pyrite gives rise to sulphuric acid and soluble sulphates which may act upon any limestone present and convert it into gypsum. This action undoubtedly accounts

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[6]Sherwin, R. S., Notes on the Theories of Origin of Gypsum Deposits: Kans. Acad. Sci., vol. 18, 1903, pp. 85-88.

for the presence of much of the gypsum disseminated through shales and sandstones and in coal. It is very doubtful, however, if any considerable deposits of gypsum have been formed in this way.

Formation of gypsum from anhydrite.—Gypsum is formed from anhydrite when the latter takes up water and recrystallizes. The volume of the gypsum formed is 33 per cent larger than that of the anhydrite and the force of the expansion is sufficient to lift considerable thicknesses of overlying strata, and to break crystals of quartz and dolomite in the layers above. Since anhydrite occupies less space than the same amount of calcium sulphate in form of gypsum, great pressures would tend to change gypsum to anhydrite and reduction of pressure would tend to bring about the change from anhydrite to gypsum. Grimsley[6] has noted the fact that samples from deep wells in Michigan show anhydrite rather than gypsum and that in boiler scale the calcium sulphate is present as anhydrite.

In Oklahoma anhydrite occurs in considerable quantities closely associated with the gypsum. A considerable bed occurs in the Medicine Lodge gypsum for 50 miles or more. Gypsum occurs both above and below it and, so far as the writer's observations go, it is impossible to tell whether or not the anhydrite is altering to gypsum. There is no apparent disturbance of the strata above the gypsum as would be expected if the gypsum had been formed from anhydrite, but in so soft rock such slight disturbances might escape notice. As to the alteration of the gypsum to anhydrite, it is very difficult to see how the conditions should bring this about and especially why the alteration should commence in the middle of the bed. The lower beds of the Greer formation are anhydritic but the anhydrite and gypsum seem to be mixed with each other throughout the mass. There is no apparent evidence of the alteration of one to the other and the writer believes that the mixture is the result of original deposition. In any case the formation of gypsum from anhydrite still leaves unsettled the question of the origin of bodies of anhydrite of sufficient size to form gypsum deposits of the magnitude of those in Oklahoma.

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[6]Grimsley, G. P., The Gypsum of Michigan: Mich. Geol. Survey, vol. 19, Pt. II, 1904, p. 185.

Deposition of gypsum by evaporation of sea water in enclosed or partially enclosed basins.—There is little doubt that most of the important gypsum deposits of the world have been formed by the evaporation of sea water. Sea water contains 3¼ per cent of mineral matter and the mineral matter is composed principally of the following salts in the percentages given:

Sodium chloride (NaCl) common salt	77.758
Magnesium chloride ($MaCl_2$)	10.878
Magnesium sulphate ($MgSO_4$)	4.737
Calcium sulphate ($CaSO_4.2H_2O$) gypsum	3.600
Potassium sulphate (K_2SO_4)	2.465
Calcium carbonate ($CaCO_3$) limestone	0.345
Magnesium bromide (MgBr)	.217
Total	100.000

When sea water is evaporated the salts are deposited in the inverse order of their solubilities, that is, the least soluble first. It should be borne in mind, however, that the solubilities of these substances in the presence of each other are quite different from their solubilities in pure water and that in the concentration of sea water many reactions probably take place before the water is all evaporated.

J. Usiglio in 1849 published the results of experiments on the evaporation of water from the Mediterranean Sea. His results are summarized by Clarke[7], who gives the following table showing the deposits at different concentrations. The amounts of the deposits are given in grams for an initial volume of 1 litre.

[7]Clarke, F. W., Data of Geochemistry: Bull. U. S. Geol. Survey, No. 491, 1911, pp. 207-209.

Salts Laid Down in Concentration of Sea Water.

Density	Volume	FE_2O_3	$CaCO_3$	$CaSO_4$ $2H_2O$	NaCl	$MgSO_4$	$MgCl_2$	NaBr	KCl.
1.0258	1.000	-------	-------	-------	-------	-------	-------	-------	-------
1.0500	.533	0.0030	0.0642	-------	-------	-------	-------	-------	-------
1.0836	.316	-------	trace	-------	-------	-------	-------	-------	-------
1.1037	.245	-------	trace	-------	-------	-------	-------	-------	-------
1.1264	.190	-------	.0530	0.5600	-------	-------	-------	-------	-------
1.1604	.1445	-------	-------	.5620	-------	-------	-------	-------	-------
1.1732	.131	-------	-------	.1840	-------	-------	-------	-------	-------
1.2015	.112	-------	-------	.1600	-------	-------	-------	-------	-------
1.2138	.095	-------	-------	.0508	3.2614	0.0040	0.0078	-------	-------
1.2212	.064	-------	-------	.1476	9.6500	.0130	.0356	-------	-------
1.2363	.039	-------	-------	.0700	7.8960	.0262	.0431	0.0728	-------
1.2570	.0302	-------	-------	.0144	2.6240	.0174	.0150	.0358	-------
1.2778	.023	-------	-------	-------	2.2720	.0254	.0240	.0518	-------
1.3069	.0162	-------	-------	-------	1.4040	.5382	.0274	.0620	-------
Total deposit.		.0030	.1172	1.7488	27.1074	.6242	.1532	.2224	-------
Salts in last bittern		-------	-------	-------	2.5885	1.8545	3.1640	.3300	0.5339
Sum		.0030	.1172	1.7488	29.6959	2.4787	3.3172	.5524	.5339

From the table it is seen that the iron in solution is deposited when approximately one-half of the water is evaporated and that over one-half of the calcium carbonate (limestone) is deposited at the same time. The remainder of the carbonate is not thrown down until over 80 per cent of the water is evaporated, and at this concentration the gypsum also begins to come down. The deposition of gypsum continues until about 97 per cent of the water is evaporated. Common sale begins to be deposited when 90 per cent of the water is evaporated. About 83 per cent of the gypsum is deposited before the salt begins to come down and the remaining 17 per cent appears mixed with the vastly larger quantity of salt. The other soluble salts come down with the sodium chloride, but the order in which they are deposited is of no importance in the consideration of gypsum.

If, then, a quantity of sea water were shut off from the ocean in an enclosed basin and evaporated to dryness without the addition of any water from the land or ocean we should expect the salts deposited in the following order: At the bottom, a layer of limestone, the lower part containing some iron; above this a layer of gypsum with the lower part containing some limestone, and the upper part grading rapidly into common salt

containing other soluble salts as impurities, and at the top a mixture of the most soluble salts. In a case of this kind there would be approximately ten times as much gypsum as limestone and twenty times as much salt as gypsum.

In nature, however, it is very seldom, if ever, that a body of water of any size could completely evaporate under such simple conditions. Connections would almost certainly be renewed with the ocean from time to time, resulting in freshening of the water and consequent disturbances of the order of deposition. Some drainage from the surrounding land would be sure to enter the basin. If this were not sufficient to cause the basin to overflow it would freshen the water and at the same time would add other mineral matter in solution. Heavy floods might bring down sufficient clay to form a layer of mud over the bottom of the basin and to freshen the water until there would be no deposition from solution for some time. Concentration might then proceed until the limestone or perhaps limestone and gypsum would be deposited when another flood would produce a second layer of mud and prevent the deposition of the more soluble salts. Thus it is evident that the simple sequence of deposition may be interrupted any number of times and that there may be many layers of mud and limestone or of mud, limestone, and gypsum deposited without the concentration proceeding far enough to deposit the more soluble salts.

The mineral matter brought down in solution would add several factors to be considered if evaporation proceeded to dryness. In the formation of the salts from the bittern or mother-liquor the temperature may affect the different combinations formed and the degree of hydration of the different salts. In many cases the connection between the ocean and the enclosed body of water was probably renewed after the deposition of the limestone and gypsum and before the more soluble salts could be deposited. Or, if the soluble salts were deposited, they were probably redissolved and carried away by ground or surface waters, leaving the gypsum and limestone. It is evident that as evaporation proceeded that the area covered by water would continually decrease and that the concentrated water would collect in the deeper parts of the basin. The salt, therefore, would be deposited over a much smaller area than the limestone and gypsum, but it would be many times as thick.

We would expect, therefore, that deposits of limestone formed by evaporation of sea water would be much more wide spread than those of gypsum and that the gypsum would be more wide spread than the salt, but that where the salt was deposited and not removed later that it would be many times as thick as the limestone or gypsum.

The noted Stassfurt deposits[8] give probably the most complete record of deposition by evaporation of a large body of water, but this record is far from being simple. More than 30 saline minerals are found in the deposits; some of them regarded as primary minerals and others as being derived from these by secondary reactions. The majority of the minerals are double salts.

The great difficulty in accounting for the formation of gypsum deposits by the evaporation of sea water is in the immense quantity of water which would be required to furnish the amount of gypsum in the deposits. Sea water probably contains as great a percentage of gypsum at present as it ever did. The thickness of the gypsum layer deposited by evaporation of a body of water 1 foot deep is only .0007 foot. To form a layer of gypsum 10 feet thick would require a depth of over 14,000 feet or 2 2-3 miles of water, if the gypsum were deposited in a basin with vertical sides.

In the case of an enclosed basin with sloping sides the depth might be much less since the area of the body would contract greatly before the gypsum was deposited, and there would also be constant additions of water containing mineral matter from the drainage into the basin. But even when these factors are considered it seems impossible to conceive of enclosed basins of sufficient size and depth to form such deposits as exist in the Permian-Triassic Red Beds of the Great Plains and Rocky Mountain States. Grimsley[9] accepts the deposition in an enclosed basin resembling the Caspian Sea as the origin of the Michigan deposits. He has worked out in some detail the area of the sea and of its drainage basin.

The conditions of deposition in partially enclosed basins have been noticed in some of the preceding paragraphs. The

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[8]Clarke, F. W., Op. cit. p. 210-217.

[9]Grimsley, G. P., The Gypsum of Michigan: Mich. Geol. Survey, vol. 9, Pt. II, 1904, pp. 187-191.

discussion of conditions as they exist in such basins at present are given by Wilder[10] as follows:

"Basins which are in some degree connected with the ocean may next be considered. The Bessarabian coast of the Black Sea furnishes an example of salt deposits in bays slightly connected with the ocean and fed from the landward side by rivers. From the Danube to the Dnieper the rivers before emptying into the ocean expand into lakes which are separated from the sea by natural dams. Under ordinary circumstances the water flows into the sea through an opening in the dam, while during storms the water of the sea enters the lakes. Three of these lakes become partially dry every summer and deposit salt which in places amounts to a layer a foot thick. This salt is used for commercial purposes. The calcium sulphate of the river water and of the sea water which is driven in during storms must also be deposited, but the quantity being small, readily escapes notice.

"Many writers on gypsum and salt have called attention to the fact that the Mediterranean Sea furnishes conditions which if but slightly modified would result in deposits of these substances. Although it receives the waters of many rivers, some of them of considerable size, evaporation takes place faster than inflow and if no water entered through the Strait of Gibraltar, or if the supply entering were considerably reduced, much of the mineral matter held in solution would be deposited. A steady current pours in from the ocean, however, and the density necessary for precipitation is not reached. The bottom of the sea rises sharply near the Strait of Gibraltar, cutting off communication between the lower part of the sea and the ocean, but permitting a free interchange of water in the upper level. The depth of the strait is less than 200 fathoms, while the average depth of the Mediterranean is 1,000 fathoms. The accompanying diagram roughly illustrates existing conditions.

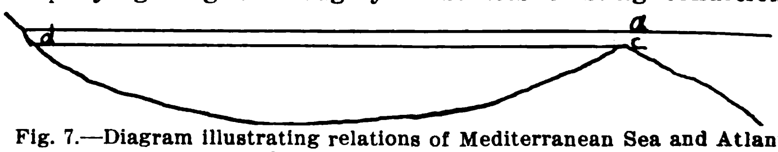

Fig. 7.—Diagram illustrating relations of Mediterranean Sea and Atlantic Ocean (after Wilder).

[10]Wilder, Frank A., Geology of Webster County: Iowa Geol. Survey, vol. 12, 1902, pp. 123-124.

"The amount of salt in the water of the Atlantic is 3.6 per cent, while in the Mediterranean it is 3.9 per cent. The specific gravity of the water of the Atlantic off the Strait of Gibraltar is 1.026, while at the west end of the Mediterranean, near the surface, it is 1.028, increasing in the east end to 1.03. At a depth of 300 fathoms the density is considerably greater than at the surface. A current of water flows in constantly at the surface of the strait (figure 7, *a*). This water is concentrated by evaporation and sinks. The bottom below the line *c d* has been previously filled by this dense water and water is being constantly condensed, sinks and flows out at *c* as a lower current into the ocean. The outlet at the strait is so free that the condensation does not reach the point which results in the deposition of lime, gypsum or salt.

"It is quite conceivable that the opening could be so restricted that the outflow would b egreatly diminished and the density of 1.05 to 1.13 which is necessary for the deposition of limestone be reached. If this were maintained for a long time and the inflow were enough to prevent further concentration a thick layer of limestone without gypsum and salt would be formed. If the opening were still further restricted gypsum would be precipitated and at length salt. In this case, however, the calcium carbonate in the inflowing sea water would be precipitated with the gypsum unless converted into gypsum or a more soluble salt by reaction with other salts or isolated during deposition as is the case today in the Great Salt Lake. The amount of the calcium carbonate (one-tenth as much as the gypsum) if present would be easily recognized. If instead of a small opening the inland sea were shut off from the ocean by a low barrier, over which the sea water passed only in time of great storms, the deposits might be more varied. The water would be diluted at times so that precipitation of the more soluble salts would cease and after a period of evaporation, if the amount of calcium carbonate in the newly added water were considerable, there would be a deposit of limestone succeeded by gypsum. A series of limestone and gypsum beds occurs in the northern peninsula of Michican near St. Ignace."

APPLICATION OF THE THEORIES OF ORIGIN TO THE OKLAHOMA DEPOSITS.

In attempting to apply any of the different theories of origin of gypsum to the Oklahoma deposits several difficulties

are encountered. The deposits are continuous on the north with those of Kansas which pass under Tertiary rocks to the northwest, and on the south with those of Texas which probably extend under younger rocks as far as El Paso. To the west the gypsums connect along Canadian River with the deposits of eastern New Mexico which are probably continuous along the eastern flank of the Rocky Mountains with those of Colorado and Wyoming. It is not meant that any individual ledges of gypsum extend over all or even a large part of this area, but that the gypsum occur at the same general horizon and under the same general conditions. Any theory which is applicable to the Oklahoma deposits must apply in large measure to the deposits of the whole area.

The almost total absence of limestone in connection with the gypsum beds in the whole area seems to preclude the possibility of the gypsum having been formed from the alteration of limestone. The entire environment of the beds suggests aqueous deposition, while at the same time all the evidence points to shallow water conditions. The presence of marine fossils, which occur in the thin dolomitic members immediately beneath some of the gypsums, is conclusive proof that there was at least occasional connection with the ocean. The oxidized character of the clays and sandstones and their general fine-grained condition indicates that the material came from rather low lying land on which chemical weathering proceeded unchecked.

The great difficulty in accounting for the deposition of gypsum in such shallow basins as seem indicated is the immense volume of water required to produce such bodies of gypsum. This has already been mentioned briefly in a preceding paragraph. Another difficulty is the almost total absence of limestone or of any carbonate rock. Usually a thin layer of dolomitic sandstone lies immediately beneath the gypsum, but it is usually much less than one-tenth the thickness of the gypsum and it is also far from being a pure carbonate rock.

The absence of limestone may be explained in three ways. In the first place, the sea water of the period may have contained less calcium carbonate in proportion to gypsum at the time of the deposition of the deposits in the Red beds than at present. Chamberlin and Salisbury[11] hypothecate this condition

[11]Chamberlin, T. C., and Salisbury, R .D., Geology: vol. 2, pp. 660 et seq.

in the Permian Sea as an important factor in the glaciation of the period. However, unless this condition was extreme it does not seem to account for the great apparent discrepancy between the theoretical and observed amounts of limestone. Besides, there was almost certainly considerable drainage into the basins and this drainage must have contained much more carbonates than sulphates unless some unknown source of sulphates existed.

It is entirely possible that the limestone if deposited with the gypsum has been altered to gypsum by the influence of the waters carrying calcium sulphates dissolved from the overlying gypsum. It seems strange, however, that if the theoretical amount of limestone was deposited with the gypsum that it should be everywhere so completely altered. The second explanation, which has been used by Wilder[12] in accounting for the absence of limestone from the Iowa deposits, is that the carbonates entering the basin after the water of the basin had become concentrated would be precipitated very near the mouths of the streams and along the shores. This action is taking place in Great Salt Lake at the present time. The fresh waters entering the lake contain considerable quantities of carbonates but the waters of the lake itself show scarcely a trace. The carbonates are removed immediately and deposited near the mouths of the streams in the form of oolitic sand. While the deposits in Oklahoma were probably not formed in wholly enclosed basins the conditions of deposition were doubtless very similar.

One case in Oklahoma seems to coincide with this conclusion. Southeast of Watonga the uppermost gypsum (Shimer) of the Blaine formation thins and finally disappears, while the dolomitic horizon thickens and prolongs the outcrop for some miles after the disappearance of the gypsums. Here the dolomite or magnesian limestone is about 5 feet thick and relatively pure. This is the only instance of this sort which is known to have been observed in detail, but when it is considered that very little detailed work has been done in the great area occupied by the gypsum and also that much of the probable gypsum bearing area is covered by younger rocks, it is easily seen that

[12]Wilder, Frank A., Geology of Webster County: Iowa Geol. Survey, vol. 12, 1902, p. 126.

many such cases might occur unnoticed. Sherwin[13] points out that probably the greater part of the drainage into the basins of deposition was from limestone regions and that consequently the stream waters would be high in carbonates. He regards the carbonates as being decomposed by sulphates or sulphuric acid derived from sulphur springs. This reaction might take place, but the presence of a sufficient number of sulphur springs to cause such deposits seems more difficult to explain than the accumulation of sufficient water to form the deposits by evaporation. There are no known areas of Permian volcanic rocks in the region which might provide a source for the sulphur. When all their features are considered, then, it seems probable that the gypsum deposits of Oklahoma were formed by evaporation of water in relatively shallow basins, which, at least temporarily, had more or less connection with the sea.

HISTORY OF GYPSUM.

The use of gypsum and of gypsum plasters has been known since ancient times. The pyramids of Egypt contain plaster work executed 4,000 or more years ago. For their finer work the Egyptians used a calcined gypsum plaster precisely similar to the plaster of Paris of modern times, and the methods of use and the tools used were also similar to the modern ones. The Greeks also used the calcined plaster in making casts, the earliest known use for this purpose.

The white compact variety known as alabaster has been used in Europe for centuries for interior decoration and ornaments, especially in cathedrals and other ecclesiastical buildings. Vases, urns, boxes for different purposes, statues and statuettes, and mural decorations were the more common articles made from alabaster. The name alabaster, however, was applied to marble and onyx as well as to gypsum and it is often difficult to tell which is meant. Selenite in large pieces or flakes was used for windows and also in making boxes or vases to surround lights for the softening effect on the illumination.

The use of gypsum both in the crude and calcined forms has continued up to the present, but the use of the calcined products has shown a rapid increase in the last few decades.

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[13]Sherwin, R. S., Notes on the theories of origin of gypsum deposits Trans. Kans. Acad. Sci., vol. 18, 1903, pp. 85-86.

In the United States the gypsum industry began in New York when the population was principally restricted to the Atlantic seaboard. As the population moved westward the development of the gypsum resources followed. The development of the important Michigan deposits began in a small way about 1840 and that of the Iowa deposits near Fort Dodge in 1872. The first plaster mill in Kansas was built in 1889, and the first mill in Oklahoma a few years later. The development of the deposits in California and along the coast began about 1875. For many years the major portion of the production was ground and sold in the raw form for land plaster. In recent years the consumption of land plaster has shown practically no increase or has decreased, while the use of the calcined products has grown very rapidly, until at present the raw products represent only a small percentage of the value of the gypsum products.

STRATIGRAPHIC DISTRIBUTION OF GYPSUM.

The age of the principal gypsum and salt deposits of the world are given in a table by Wilder[14] which is given herewith.

Foreign	*American*
Pleistocene and Recent	
Caspian Sea and Asiatic Lakes.	Great Salt Lake.
Pliocene	
Transylvania, near Prague (salt). Caspian Sea in Karabhogas Bay (salt and gypsum). Austria at Wieliczka, Siebenburgen (salt and gypsum).	
Miocene	
None	
Oligocene	
Transylvania and Carpathian Mts. (gypsum and salt). Germany, Sperenberg (gypsum). France, Montmartue (gypsum).	
Eocene	
None	

[14]Wilder, Frank A., Geology of Webster County: Iowa Geol. Survey, vol. 12, 1902, pp. 114-115.

	Cretaceous
	None
	Jurassic
	None
	Triassic
Germany: Hanover, Austadt. Erfurt, Thuringia. Lothringen (gypsum and salt). England: From Scotland to Devonshire (gypsum and salt)	Black Hills (gypsum).
	Permian
Germany: The Hartz (gypsum). Stassfurt, Sperenberg (gypsum and salt). South Tyrol (gypsum). Russia (gypsum, salt).	Iowa (gypsum) Texas (gypsum). Kansas (salt and gypsum) Oklahoma and Indian Territory. Black Hills (gypsum).
	Upper Carboniferous
	None
	Lower Carboniferous
	Lower Michigan (gypsum). Nova Scotia (gypsum and salt). Virginia (gypsum and salt). Montana (gypsum).
	Devonian
	None
	Silurian
Russia, Baltic provinces, (gypsum).	New York (gypsum and salt). Ohio (gypsum and salt). Pennsylvania (gypsum). Upper Michigan (gypsum).
	Ordovician
	None
	Cambrian
Punjab Salt Range, India.	

In addition to the deposits mentioned in the table the following should be noted: (1) Gypsum and salt in the Pennsylvanian rocks in Kimberly district, Australia[15]; (2) the great deposits of the Rocky Mountain region and the great basin in Wyoming, Colorado, New Mexico, Arizona, Utah, and Nevada, probably ranging in age from Pennsylvanian to Jurassic; (3)

gypsum in southwestern Germany[16], and in Sussex, England[17], in the upper Jurassic (Purbeckian); and (4) the gypsum and sulphur deposits in the northern Apennines of Italy in the Pliocene.

From the table and notes it will be seen that the more important gypsum deposits are grouped into the Silurian, Permian, and Triassic, in America and Europe, with important deposits in Europe in the Oligocene and Pliocene and in America over restricted areas in the Mississippian. In general it may be said that widespread deposition of gypsum took place in those periods marked by large expanse of land. This is particularly noticeable in the Permian and Triassic in Europe and America, and the Pliocene in Europe. The periods of widespread submergence or of expansion of the water areas. Cambrian (except in northern India), Devonian, Ordovician, Mississippian (except for restricted areas in North America), Cretaceous, Eocene, and Miocene have no important gypsum deposits.

AREAL DISTRIBUTION OF GYPSUM.

The distribution of gypsum deposits outside of the State is of prime importance to the industry in Oklahoma, since this distribution, in large measure, controls the conditions of competition. In the following paragraphs the distribution in foreign countries is noted very briefly and that in the United States somewhat more fully.

Foreign.

Australia.—Gypsum occurs in layers in the Rolling Downs formation (Lower Cretaceous) and Desert sandstone (Cretaceous) in Queensland[18]. The beds are usually thin. Gypsum occurs in the beds of dry lakes and in Carboniferous beds in Western Australia. Large deposits are also reported from New South Wales, but they are too far from transportation to be utilized. Gypsum is produced commercially in Victoria.

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[15]Geikie, O., Text Book of Geol.: 4th Ed., p. 1059.
[16]Op. cit., p. 1153.
[17]Prestwich, Geology: vol. 2, p. 233.
[18]Grimsley, G. P., The Gypsum of Michigan: Mich. Geol. Survey, vol. 9, pt. II, 1904.

India.—Gypsum occurs in immense quantities in Northern India, principally in the Salt Range. Some of the deposits are of Eocene age, but the more important ones are in rocks which are probably Cambrian. Deposits are known in Afghanistan and Baluchistan. The production is small, not exceeding 5,000 tons annually.

Italy.—Gypsum occurs as alabaster in the lower part of the Pliocene of the northern Apennines. The mines at Volterra have been worked for a long period of time.

Australia.—Immense beds of rock salt and gypsum are present in Pliocene strata in the northern flank of the Carpathian Mountains at Wieleczka near Cracow. In the same general region and in Transylvania gypsum and rock salt occur in the Oligocene.

Crete.—Gypsum occurs in beds in the upper Triassic on the island of Crete.

Cyprus.—Gypsum deposits are worked on both the east and west coasts of Cyprus. The rock is calcined and used for building material on the island and is exported to Turkey and Egypt.

France.—The important gypsum deposits of the Paris Basin are in upper Eocene strata. The highest and most important bed is 65 feet thick at Montmarte. It is a fresh water deposit, containing bones of mammals, terrestial shells, and wood, conformable on marine deposits below. Three bands of gypsum occur lower in the Eocene. The product from this area has given the name of plaster of Paris to calcined gypsum the world over. The rock is worked by means of quarries, drifts, and shaft mines. The gypsum is rather impure, carrying as high as 10 to 12 per cent of calcium carbonate, which, however, does not seem to impair the plaster.

Germany.—Gypsum and rock salt beds are intercalated with fresh water limestones in the upper Jurassic (Purbeckian) in Westphalia and in northwestern Germany. The important deposits, however, occur in the upper Triassic in Hanover, Austadt, Erfurt, Thuringia, and Lothringen; and in the upper Permian in the Hartz Mountains, Stassfurt, and Sperenberg.

England.—Gypsum occurs in commercial quantities in Staffordshire, Derbyshire, Nottinghamshire, Cumberland, West-

moreland, and Sussex. The rock occurs as nodules and lenticular beds up to 15 feet in thickness. The principal deposits are of upper Triassic age, but those in Cumberland and Westmoreland are Permian and those of Sussex are upper Jurassic. The deposits have been worked for generations and utilized in various ways. The annual production for several years has been about 200,000 to 225,000 tons.

Canada.—The gypsum deposits of eastern Canada have been described recently by Jennison[19] and his summary is as follows:

"Gypsum deposits of economic importance are found in most of the provinces and territories of the Dominion of Canada. Those having the greatest area, and most accessible, are found in the eastern provinces, where they occur in the lower Carboniferous formation, and are practically inexhaustible.

"In British Columbia large deposits of gypsum occur associated with grey schists and white crystalline limestone. They are found north of the middle crossing of the Salmon river, and have a thickness of over 100 feet. They are also found in the vicinity of Spence's Bridge.

"In Alberta, on the Slave river, 40 miles above Smith's landing, there is an outcrop of limestone, associated with some gypsum and mineral tar. It is also found one mile south of the forks of Salt river. The exposure is 20 feet thick and interbedded, and has underlying it thin layers of red clay.

"In Manitoba, at St. Martin lake, 10 miles west of the outlet of Little Saskatchewan river, gypsum deposits are found of considerable importance. The exposures are worked as open quarries, and the product hauled in the winter season to the shores of Lake Manitoba by team; after manufacturing it is shipped by steamer to Westbourne railway station. The rock is exposed on a number of outcrops, the highest being 60 feet above St. Martin lake. Some anhydrite is seen, and large quantities of selenite. Geologically its position is either that of the lower Devonian or upper Silurian, probably the Salina formation.

[19]Jennison W. F.. Gypsum deposits of the Martime Provinces: Canada Dept. of Mines, Minech Branch, No. 84, 1911, p. 21.

"In Ontario a small amount of gypsum is mined yearly; it occurs on the Grand river, in the vicinity of Paris, in Brant county. The gypsum formation extends from the Niagara river to Saugeen, a distance of 150 miles. Its occurrence is in veins from 2 to 7 feet thick and separated into several layers.

"In Quebec the principal deposits occur in the lower Carboniferous measures of the Magdalen islands.

Newfoundland[20].—The gypsum deposits of this island occur on the west coast. Geologically they are in the same position and resemble those of Nova Scotia. They occur in extensive beds, with prominent exposures on Romaine brook, at Piccadilly, south side of Port-au-Port bay, and at different points on the south side of St. George bay. The rock is white, and in texture, both compact and granular; very little anhydrite is seen."

United States.

Virginia[21].—The commercial gypsum deposits of Virginia

Watson, T. L. Mineral resources of Virginia: 1907.

occupy a narrow belt about 16 miles long in Smyth and Washington counties in the southwestern part of the state. Intimately associated with the gypsum are considerable salt deposits. Both substances are in shales of Mississippian age which underlie the Greenbrier limestone. The gypsum bearing shales outcrop around a syncline and the dip of the rocks is so steep that mining methods are necessary. The bodies of gypsum are large masses and lenses interbedded with red and gray clays and contain much irregularly distributed anhydrite. The average thickness worked is 30 feet. Commercial development of the deposits began early in the nineteenth century and several companies have operated in the region at different times. In 1910 and 1911 two mills were working at Plasterco and Saltville. The various forms of hard wall plaster are the principal products, but large quantities of the raw gypsum are ground and used as land plaster. Between 1890 and 1906 the annual production ranged from 6,000 to 20,000 tons and between 1890 and 1902 the value ranged from $17,000 to $45,000. Statistics for the past few years are not available on account of there being only two producers.

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[20]Op. cit., p. 23.
[21]Eckel, E. C., Bull. U. S. Geol. Survey Nos. 213, 1902 and 223, 1904.

New York[22].—The gypsum deposits of New York are found in the Salina group, the upper part of the Silurian system. The Salina outcrops in an east-ward belt from 10 to 20 miles wide, about the same distance back from the south shore of Ontario. The section in a mine at Lindlen shows 7 beds of gypsum ranging from 4 to 11 feet in thickness separated by shale bands from 1 to 2 feet thick. The beds thin in both directions from Cayuga lake. To the east the beds become impure and are not of commercial importance east of Madison county. Most of the rock is dark colored and too impure to be used for the finer grades of plaster of Paris, but in the western end of the belt some of them are of high grade. For many years practically all of the output was sold crude for land plaster and the manufacture of the calcined plasters was not begun until later than it was in Ohio, Michigan, and Iowa. The gypsum, especially in the western part of the area, has proven suitable for wall plaster and in the past few years the manufacture of wall plaster has increased very rapidly while the production of land plaster has remained almost stationary; so that, at present, the calcined products make up the greater part of the output. Large quantities of the crude and calcined gypsum are used by the Portland cement mills of New York and Pennsylvania. The amount of material in the New York deposits is very great and so far only those deposits advantageously situated in regard to transportation have been developed. Most of the development is by quarries or open cuts but several drifts and shaft mines are used. Thirteen mills were reported as operating in 1910[23] and 12 mills in 1911. The total production in 1910 was 467,399 tons with a value of $1,153,973, and in 1911 was 472,834 tons with a value of $1,199,596. About two-thirds of the crude gypsum is calcined and the value of the plaster in 1912 was four-fifths of the value of the total output.

Ohio[24].—The gypsum deposits of Ohio are confined to small areas near Sandusky bay. The beds occur near the top of the Silurian system in the Rondout formation. On the north shore of the bay, southeast of Port Clinton, 150 to 200 acres of workable gypsum have been shown by core drilling. Another area has been prospected about 2½ miles north of Castalia on the

[22]Eckel, E. C., Bull. U. S. Geol. Survey No. 223, 1904, p. 33-35.

[23]The statistics given for the various states are taken from the Mineral Resources of the United States for 1911, U. S. Geol. Survey.

[24]Peppel, S. V., Gypsum deposits in Ohio: Op. cit., pp. 38-44.

south shore of the bay. Some of the drill holes on the north side of the bay show as many as 8 beds of gypsum varying from 18 inches to 10 feet in thickness separated by limestones from 3 to 10 feet thick. The gypsum where worked is as much as 9 feet thick. It is a rock of a grayish cast due to numerous fine wavy bands of bituminous material. There are occasional thin shaly partings having irregular courses through the gypsum rock. The material was first worked by open quarries but most of it is now obtained by under ground workings. Water gives considerable trouble. Two plants were operated in 1910 and three in 1911, all on the north shore of Sandusky bay near Port Clinton. On account of the small number of producers the statistics of production are not made public. The combined production of Virginia and Ohio in 1910 was 292,987 tons of crude gypsum with a value of $821,213, and in 1911 was 369,858 tons with a value of $1,056,568. Ohio probably furnished considerably over half the combined production.

Michigan[25].—Gypsum is known to occur in two localities on the Lower Peninsula, at Grand Rapids near the western coast and at Alabaster on the eastern coast. The deposits are found in the lower Grand Rapids series of Mississippian age, which outcrops as a ring around the interior coal basin. The deposits at Grand Rapids consist of an upper ledge 6 feet thick separated by about 1 foot of shale from a lower ledge 12 feet thick. At Grandville there is a ledge 11 feet thick separated by 4 feet of limestone from a lower ledge 14 feet thick. The gypsum is a massive rock gypsum of a high degree of purity. It is worked both by quarries and underground workings. The Alabaster quarry is at Alabaster, three-fourths of a mile back from the shore of Saginaw bay. The bottom of the quarry is about 15 feet above the water level. The face of the quarry is 16 to 22 feet high and more than one-fourth of a mile in length. The cover consists of about 10 to 12 feet of stiff bowlder clay which is removed by a steam shovel. In addition to these deposits on the Lower Peninsula, gypsum is known to occur at St. Ignace in the Upper Peninsula but it is not utilized and little is known concerning its extent or value. It is found in rock of the Monroe group of Saline age. Eight mills were

[25]Grimsley, G. P., Gypsum deposits in Michigan: Bull. U. S. Geol. Survey, No. 223, 1904, pp. 45-47; and The gypsum of Michigan: Mich. Geol. Survey, vol. 9 Pt. II 1904.

erated in Michigan in 1910 and 1911, 7 near Grand Rapids d 1 at Alabaster. In 1910 the total output of crude gypsum is 357,174 tons and the total value of the products was $668,- 1, and in 1911 the total output was 347,296 tons with a value $573,926. The value of the calcined products is over four- ths of the total.

Iowa[26].—The gypsum area of Iowa occupies 60 or 70 square les near Ft. Dodge, Webster county, near the center of the ite. The gypsum occurs as a single bed made up of several yers separated by extremely thin clay partings. It is asso- ated with red clay and is probably of Permian age. The bed covered, except immediately along the Des Moines river and tributaries, by a mantle of glacial drift 60 to 80 feet in ickness. The thickness of the gypsum bed is variable on count of the pre-glacial erosion. Where it is fully developed e following divisions are recognized:

Division of Gypsum Bed in Iowa.

	Feet.
Upper rock, suitable for plaster, varying in thick ness on account of difference due to loss by pre- glacial erosion	3 to 12
Six-foot ledge, best of the plaster rock	6
Hard ledge, inferior for plaster	4
Eighteen-inch ledge, not good for plaster	1½
Bottom ledge, not good for plaster	5

The material is a dense, fine-grained rock, with alternating reen and white bands about one-half inch thick. The micro- cope shows that it consists of a mass of minute crystals. The evelopment of the Iowa gypsum began in 1872. The mills long the Des Moines river and its tributaries strip the gypsum nd operate quarries. Back on the prairie the stripping is too hick for quarrying and the material is reached through shafts. The upper part of the bed is left for a roof. Six plaster mills nd one paint mill using gypsum were operated in this field in 910 and 1911. The output in 1910 was 322,713 tons of crude ypsum and the value of the products was $943,849, and in 1911 the output was 354,204 tons, and the value, $857,287.

[26]Wilder, Frank A., Gypsum deposits in Iowa: Bull. U. S. Geol. Survey No. 223, 1904, pp. 49-52; and Geology of Webster County: Iowa Geol. Survey, vol. 12, 1902, pp. 99-166.

Practically all the gypsum produced in Iowa and the states the southwest is calcined. The value of the gypsum sold cru in Iowa, Kansas, Oklahoma, and Texas in 1911 was $66,... The most of this product went to Portland cement plants. L than 5,000 tons were sold for land plaster in the four states.

Kansas[27].—The gypsum deposits of Kansas occur in a l crossing the state from north to south a little east of the mid of the state. The three principal areas are near Blue Rap in the northern part of the area, near Gypsum City in t central part, and near Medicine Lodge in the southern pa The deposits in the northern portion are in the lowest pa of the Permian rocks, those of the central area are higher the system and those near Medicine Lodge are near the t of the system as exposed in Kansas. The last named beds a the continuation of the main line gypsum hills of Oklahom Both rock gypsum and gypsite or earth gypsum are prese in almost inexhaustible quantities. The gypsite is most abun ant in the central area. Plaster has been manufactured in t state since 1875. Seven mills were operating in 1909 and 19 and six mills in 1911. During the last few years the value the annual output has been between $300,000 and $400,000.

Oklahoma.—The gypsum deposits of Oklahoma occur in t Permian Redbeds in the western portion of the State. Th consist of rock gypsum and gypsite deposits. The commerci deposits may be divided into three areas: (1) The first line gypsum hills, along Cimarron river, (2) the second line of hil including parts of Dewey, Custer, Washita, Caddo, and Stephe counties, and (3) the Southwestern Area in the extreme sout western part of the State. The gypsum of the first line hills occurs in 3 beds separated by clay shales. The stratificatio in the second line of hills is very erratic, and the gypsums a not continuous over large areas, but some of them reach thickness of over 60 feet. There are 5 ledges in the south western area, some of them reaching a thickness of 20 feet Mills are located at Watonga (2), Bickford, Wilson, Alv Southard, Okeene, Rush Springs, Ferguson, and Eldorado i the gypsum area, and at McAlester in the eastern part of th State. All the gypsum is secured from hillside quarries an

[27]Grimsley G. P., Gypsum and gypsum cement plasters: Univ. Geol. Sur vey of Kans., vol. 5, 1899, pp. 48-50.

gypsite is worked with drag scoops or wheeler scrapers. total gypsum mined in 1910 was 162,788 tons and the value he products was about $450,000, and in 1911 the gypsum ed was 108,653 tons and the value was $287,591.

Texas[28].—The gypsums of the southwestern area of Okla-a continue into Texas as far as Colorado river, maintaining same general characteristics which they possess in Oklahoma. econd area is in the eastern part of El Paso county, east he Guadalupe mountains. The stratigraphy and the gypsums mble those of the first area and the deposits were probably ned continuously although the outcrop is interrupted from orado river to the Pecos by a covering of younger rocks. hird area is in the Malone mountains, where the gypsum n Jurassic or Cretaceous rocks. The area is near the South- Pacific Railway but is distant from any large market and not been developed. The gypsums of the second line of ls in Oklahoma continue up Canadian river across the Pan-idle of Texas and connect with the large deposits in eastern w Mexico. Gypsum is found disseminated through the etaceous rocks in the eastern part of the State but not in nmercial quantities. Three plants operated in Texas in 1910 d four in 1911. All are in the northern part of the first ea in the vicinity of Quanah. The output of crude gypsum 1910 was 188,559 tons and the value of the products was out $490,000, and in 1911 the output was 179,625 tons with value of $486,162.

South Dakota[29].—The Spearfish formation, made up of edbeds of Permian or Triassic age, outcrops in a belt around lack Hills dome in western South Dakota and eastern Wyoming. he outcrop of the gypsum-bearing rock averages about 3 miles width. The thickness of the gypsum varies greatly, but cally over 30 feet of pure white gypsum occurs. The beds re formed at different horizons; some are continuous for long istances while others are lenticular. Transportation facilities re near the beds at Hot Springs, Rapid City, Spearfish, New-

[28]Bike, W. R., Gypsum beds in southern Arizona: Am. Geol., vol. 18, 1896, No. 223 1904, pp. 68-73; and Gould, Chas. N., Geology and water resources of he Panhandle of Texas; Water-Supply Paper U. S. Geol. Survey Nos. 154 and 191.

[29]Darton, N. H., Gypsum deposits in South Dakota: Bull. U. S. Geol. Survey, No. 223, 1904, pp. 76-78.

castle, and Edgemont. A mill was formerly operated at H. Springs, but in 1910 only 2 plants, one near Rapid City and one at Spearfish, were operating. In 1911 another plant near Rapid City was added to the list. In the statistics the production of South Dakota is combined with that of several other states and cannot be stated accurately.

Montana[30].—The gypsum beds of Montana occur intercalated with red and green shales and limestones of Mississippian age, which are immediately overlain by Jurassic limestones. The important deposits are in Carbon and Cascade counties on the eastern flanks of the Rocky Mountains. The rocks lie at steep angles near the mountains and nearly level at a short distance away. The beds range from a few feet to as much as 50 feet in thickness. Mills are located at Armington, Bridger, and Riceville, but only at Riceville was there production in 1910. The production is combined with that of several other states in the published statistics and cannot be given.

Wyoming[31].—The deposits of gypsum of economic importance in Wyoming are in the Red Beds of Permian or Triassic age. These rocks are exposed around the base of most of the mountain ranges and in the cores of the smaller folds where there has been sufficient erosion to remove the overlying rocks. The areas where the gypsums are known to occur are as follows: Rawlins uplift, Freezeout Hills, Grand Canyon of the Platte, Black Hills, and the Laramie, Medicine Bow, Shirley, Seminole, Ferris, Rattle Snake, Bighorn, Owl Creek, Absaroka, Prior, Wind River, Gros Ventre, and Salt Creek mountains. In all there are about 1,500 miles of the gypsum-bearing formations exposed, and the gypsums ordinarily vary from 5 to 20 feet in thickness and occasionally reach a thickness of 30 to 50 feet. There are also important gypsite deposits known along the base of the Laramie Mountains. Most of the gypsum deposits are at considerable distance from transportation and the only development so far has been in the vicinity of Laramie. In 1910 and 1911 three mills—two of them at Laramie using gypsum and one at Red Butte, 10 miles south of Laramie, using rock gypsum—were reported. In 1911, 44,687 tons of raw material were used and the products were valued at $116,237.

[30]Weed, W. H., Gypsum deposits in Montana: Op. cit., pp. 74-75.
[31]Knight, Wilbur C., Gypsum deposits in Wyoming: Op. cit. pp. 79-85.

Colorado[32].—The principal gypsum deposits of Colorado are massive beds which outcrop at intervals along the eastern foothills of the Rocky Mountains. They occur in series of red sedimentaries usually referred to as the Jura-Trias. The gypsum reaches a thickness of 30 feet and much of it is of a good quality. The beds have been worked at Loveland, Morrison, Perry Park, Colorado City, and Canyon. The supply is regarded as inexhaustible. Other deposits occur near the station of Gypsum on the Rio Grande Railroad in the western part of the State, also in the San Juan mining region, to the east of the La Sal Mountains, and near Rico in the southwestern part of the State. At the last named locality a bed of gypsum 30 feet in thickness, which has been locally removed by solution, has played an important part in the deposition of the ores of the area[33]. All of these deposits are of Carboniferous age. None of those in the western and southwestern portions of the State have been utilized to any extent.

In 1910 and 1911, 4 mills were operated at Loveland, Canyon City, Ruede, and Portland. The last named mill uses gypsum from Coaldale. The production of crude gypsum in 1910 was 45,280 tons and the value of the products was $118,809; and in 1911 the production was 26,226 tons with a value of $59,936.

New Mexico[34].—The Red Beds of the Permian or Triassic age, which are gypsum bearing over a great territory in the Rocky Mountain and Great Plains regions, occupy great areas in New Mexico. The largest area lies in the eastern part of the State, principally in the valley of the Pecos River. Outcrops along Canadian River connect this field with the vast area of Kansas, Oklahoma, and Texas. The other large areas are in the Rio Grande valley south of the center of the State and the Zuni or Western Region. Very little detailed geologic work has been done on these areas, but gypsum is known to be extremely abundant. A remarkable accumulation of white gypsum sand forming dunes covers an area of about 350 square miles in Otero county. The development of the gypsum of New

[32]Lakes, Arthur, Gypsum deposits in Colorado: Op. cit., pp. 86-88.

[33]Ransome, F. L.; Rico folio (No. 130) Geol. Atlas U. S., U. S. Geol. Survey, 1905.

[34]Herrick, H. N., Gypsum deposits in New Mexico: Bull. U. S. Geol. Survey No. 223, 1904, pp. 89-90.

Mexico is greatly hindered by the distance to markets and the excessive freight rates. Several projects have failed on this account. In 1910 only one mill, located at Came, Chaves county, was reported as operating. Small amounts of raw gypsum are quarried at El Rito and the white sands near Alamagordo are used in a small way. The production of New Mexico cannot be given since it is combined with that of several other States in the published statistics.

Arizona[35].—Several localities are known in southern Arizona where gypsum can be obtained in quantity, the principal one being: (1) The Santa Rita Mountains, Pima County, southeast of Tucson, (2) the low hills along the course of san Pedro River in Cochise and Penal Counties, (3) the Sierrita Mountins south of Tucson, (4) the foothills of the Santa Catalina Mountains north of Tucson, and (5) Fort Apache Reservation in Navajo County. In the first named locality the gypsum beds are of considerable thickness and extent and are about 10 miles from the Southern Pacific Railway. The age of the beds is probably Permian or Triassic. The other deposits are apparently small. The deposit north of Tucson has furnished material for plaster used in that town. The deposits on Fort Apache Reservation consists of large selenite crystals. In 1910 gypsum quarried near Winslow, Navajo County, was shipped to plaster mills at Los Angeles, Cal., and a mill at Douglas utilized gypsum quarried near that place.

Utah[36].—The more important gypsum deposits of Utah occur in the central and southern portions of the State, in Juab County, east of Nephi; in Sanpete and Sevier Counties, near Saline; in Millard County, at White Mountain near Fillmore; and in Wayne Couny in South Wash. All are of rock gypsum except the one at Fillmore which consists of granular and crystalline gypsum blown up from the bed of a dry lake. The deposit at Nephi is one of the largest deposits in the United States. It forms the entire mass of prominent spur at the entrance to Salt Creek Valley and outcrops from the level of the creek up the slope in a southwesterly direction in the form of

[35]Blke W. R., Gypsum beds in Southern Arizona: Am. Geol., vol. 18, 1896. p. 394; and Gypsum deposits in Arizona: Bull. U. S. Geol. Survey No. 223. 1904, pp. 100-101.

[36]Boutwell, J. M.. Gypsum deposits in Utah: Bull. U. S. Geol. Survey No. 223, 1904, pp. 102-109.

a vertical bed or lens. The exposed portions of this body are from 275 to 300 feet in thickness, 500 feet in height along the bedding, and at least 200 feet in length along the strike. The entire thickness is of gypsum but the quality of the material varies in different parts of the body. Two beds, one 55 and the other 65 feet thick, are designated as first class gypsum. The age of the Nephi deposit, as well as that of the other rock gypsum bodies, is somewhat in doubt but they have been referred to the Jurassic. The gypsum sands at White Mountain near Fillmore are late Tertiary or Quaternary. In 1910, four mills produced plaster,—one at Nephi, one at Levan, and two at Sigurd. The raw gypsum consumed totaled 46,279 tons and the products were valued at $149,089.

Nevada[37].—The important gypsum deposits of Nevada occur in the northwestern part of the State, in the Humboldt Mountains near Lovelocks and in the Virginia Mountains halfway between Carson and Virginia. The deposits are large and easily accessible to the railway. The rocks are strongly folded and crumpled and the beds of gypsum dip at high angles. Limestone is associated with the gypsums. The age of the deposits is almost certainly Triassic. Other deposits are known in southern Nevada in rocks of probable Jurassic and of Carboniferous age. Considerable beds are known in the Tertiary or later lake beds which are widely distributed over the State. They have not been utilized. Four mills manufactured plaster in 1910,—two at Moundhouse; one at Reno in the northwestern part of the State, and one at Arden, Clark County, in the extreme southeastern portion. Most of the product goes to supply the California markets. The production can not be stated accurately but its value is probably in excess of $250,000.

California[38].—The gypsum deposits of California occur in the southern part of the State. They may be divided into four general types according to their origin—(1) efflorescent deposits, (2) periodic-lake deposits, (3) interbedded deposits, and (4) veins. The efflorescent deposits are of gypsite which has been formed by evaporation of water which has passed through gypsiferous rocks. They are confined to the region of the Coast Range. The deposits are usually shallow and of small

[37]Louderback, George D. Gypsum deposits in Nevada: op. cit. pp. 112-118.
[38]Hess, Frank L., A reconnaissance of the gypsum deposits of California: Bull. U. S. Geol. Survey No. 413, 1910.

extent. The material is often too impure to be used for plaster. Some of the localities where beds are known to occur are Mendota, Coalinga, Dudley, the Lost Hills, M'Kittrick, Sunset, Bakersfield, in San Benito County, east of the Carrizo Plain, and at Carona. The periodic-lake deposits are formed by the evaporation of the water of the intermittent lakes which are abundant in the arid regions of the southern part of the State. These deposits are reported from near Dudley, Kern Lake, Buena Vista Lake, and at Amboy in the Mojave desert where the material is worked for a plaster mill. The interbedded deposits consist principally of thin layers of gypsum, from a fraction of an inch to 3 or 4 inches thick, interstratified with much more impure clayey material. Many of the deposits are too impure to be worked and the only large beds of pure gypsum known are in the Palen Mountains too far from a railroad to be worked with profit. All the interbedded deposits are of Miocene age. The principal deposits are located as follows: on Santa Barbara Creek, French Point, Point Sal, Castaic, Palendale, in the Palen Mountains, in the Maria Mountains, at Necca, and at other places in the Colorado Desert. The vein deposits are unimportant. In 1910 gypsum was ground for land plaster or wall plaster at 9 mills in the State. During that year 45,901 tons of raw material were produced and the products were valued at $242,203. In 1911 the production was 43,855 tons and the value $204,264.

Oregon[39].—The only known commercial deposit of gypsum in Oregon occurs near the middle of the east boundary line on a ridge separating Burnt River and Snake River, 4 miles from Huntington. The gypsum occurs as elongated lenses, 20 to 40 feet thick, in a series of sedimentary rocks with intercalated volcanic tuffs, all probably of early Mesozoic age. The gypsum is in part white and crystalline; in part, however, it contains thin strata and films of a greenish chloritic mineral. Open quarry methods are used in securing the material, which is then carried on an aerial cableway to the railroad on Snake River and hauled 10 miles to Lima where it is burned into plaster. Another deposit, partly gypsite, is reported near Bend Creek in Crook County, but it has not been developed.

[39]Lindgren, Waldemar, The gold belt of Blue Mountains in Oregon: 22d Ann. Rept., U. S. Geol. Survey, Pt. II 1901 pp. 639 and 753; and Gypsum deposits in Oregon: Bull. U. S. Geol. Survey No. 223 1904, p. 111.

Idaho[40].—Gypsum occurs in Washington County in the bluffs overlooking Snake River about 10 miles from Huntington, Oregon. The material consists of lenticular masses of rock gypsum 6 to 20 feet thick, which are apparently of the same series as the deposits near Lime, Oregon. Mining methods must be used to secure the gypsum in large quantities. A railroad passes down the Oregon side of Snake River, sufficiently near for the rock to be carried to it from the bluffs on an aerial cable way. So far the deposit has not been developed beyond the prospecting stage.

Alaska[41].—Gypsum is known to occur in workable quantities in one locality in southeastern Alaska, on the east shore of Chicago Island. The deposit is of very pure gypsum, and is considerably over 50 feet in thickness. The age of the rocks is probably early Mesozoic. The extent of the deposit is not known but it is ample to provide a large supply of material. A railroad one mile in length carries the rock from the mine to a wharf where it is loaded on hulks or barges and shipped to mills on Puget Sound.

[40]Burchard, Ernest F., Mineral Resources of the U. S., U. S. Geol. Survey, 1910.

[41]Wright Chas. W., The building stones and materials of Southeastern Alaska: Bull. U. S. Geol. Survey No. 345, pp. 124-125, 1908.

CHAPTER II.

THE MANUFACTURE OF GYPSUM PRODUCTS.

EFFECT OF HEAT ON GYPSUM.

The greater part of the value of gypsum in the industries depends on the fact that under the influence of a moderate degree of heat three-fourths of the water of crystallization is given off. The gypsum whose formula is $CaSO_4.2H_2O$ becomes $(CaSO_4)2.\ H_2O$. The water begins to come off below 100°C. (212°F.) but is given up very slowly until a temperature of about 130°C. (266°F.) when it is liberated very rapidly. The $(CaSO_4)2.\ H_2O$ thus formed is ordinarily known as plaster of Paris. When it is mixed with water the $(CaSO_4).2H_2O$ takes up water and recrystallizes as gypsum. This "setting" is the property which renders the calcined gypsum of value for plaster in its various forms.

At 163°C. (325°F.) more water is given off and from this temperature to 221°C. (430°F.) little or no change takes place in the material, but above this temperature the plaster takes up water very slowly and sets only after several hours. If heated above 343°C. (430°F.) little or no change takes place in the material, but above this temperature the plaster takes up water very slowly and sets only after several hours. If heated above 343°C. (650°F.) the plaster is completely dehydrated, *i. e.*, it becomes $CaSO_4$ or anhydrite and the crystalline structure is destroyed. It will not set and is said to be "dead burned." At higher temperatures the anhydrite melts, forming a crystalline mass on cooling.

THEORY OF THE SET OF GYPSUM PLASTER.

The principal work in America on this subject has been done by G. P. Grimsley in connection with his work on the

gypsums of Kansas and Michigan. His review of the work of earlier investigators and his conclusions are here given in full[42].

"When water is added to plaster of Paris, it sets in a solid mass. This is all that it is necessary for the plasterer to know in order to do his work, but to many of these men the subject of the true nature of the set is an interesting and puzzling problem. Just what is the process of setting of plaster?

"As far as we can learn from the chemical and physical literature, this question was first answered by that famous French chemist, Lavoisier, who in 1765 described the results of his experiments in the following words, translated from the French:

''I took the calcined plaster, as has been described before, and which hardens readily with water. I threw it into a considerable amount of water, in a pan or large dish. Each molecule of plaster, in passing through the liquor, seized its molecule of water of crystallization, and fell to the bottom of the dish in the form of small brilliant needles, visible only with a strong lens. These needles, dried in the free air or with the aid of a very moderate heat, are very soft and silky to the touch. If placed on the stage of a miscroscope, it is perceived that what was taken under the lens for needles are also parallelopipeds, very fine, so they are described as thicker, or many times thinner, and many more elongated. The plaster in this state is not capable of uniting with water, but if it is calcined anew, these small crystals lose their transparency and their water of crystallization, and become again a true plaster, as perfect as before. One may, in this fashion, successfully calcine and recrystallize the plaster even to infinity, and consequently give it at will the property of seizing water.'

"This explanation of the set of plaster through the formation of a crystalline net work was verified a number of times later, and was given by Payen in 1830 as his first principle in the chemistry of plasters.

"The next important contribution to the chemistry of plaster was by Landrin in 1874, who divided the set of plaster into four periods:

[42]Grimsley, G. P., Mich. Geol. Survey, vol. 9, 1904 pp. 135-139.

" '1. The calcined plaster, on contact with water, unites with this liquid and takes a crystalline form.

" '2. The plaster dissolves partially in water, which becomes saturated with this salt.

" '3. A part of the liquid evaporates, due to the heat set free in the chemical combination. A crystal is formed and determines the crystallization of the entire mass; a phenomenon which is analagous to that which takes place when a piece of sulphate of soda is placed in a saturated solution of this salt.

" '4. The maximum hardness is reached when the plaster gains enough water to correspond exactly with the formula $CaOSO_3$, $2H_2O$; this maximum being to the remainder in proportion to the quantity of water added to the plaster to transform it into mortar.'

"Chatelier in 1887 showed that plaster would set in a vacuum flask, so that evaporation was not a necessary step in the set of plaster, as Landrin maintained in his third principle above.

"According to Le Chatelier, the plaster of Paris compound $(CaSO_4)2.2H_2O$ dissolves in part in the added water, which diminishes the solubility, and the solution becomes supersaturated and $CaSO_4$, $2H_2O$, or gypsum, crystallizes out. In other words, the plaster of Paris dissolves, and becomes hydrated, then crystallizes out as gypsum, and every particle of the plaster goes through these steps.

"My own experiments agree then with those given by Lavoisier, Payen, Landrin, and Chantelier, in that the set of plaster is due to the formulation of crystalline network. The cause of the formation of this network of crystals, or the factor which starts th ecrystallization, is the troublesome part to explain, and this has attracted less attention among investigators along these lines.

"When gypsum is burned it forms, as Landrin showed and as analyses prove, the hydrate $(CaSO_4)2.H_2O$. Marignac called attention to the fact that if water is added in excess, this hydrate in part is dissolved, forming first a clear liquid which then becomes turbid, and crystals of $CaSO_4.2H_2O$, or gypsum are thrown down. How an examination of these formulae shows

that three parts of water have been taken up by the hydrate. $(CaSO_4)2. H_2O+3H_2O=2(CaSO_4,2H_2O)$.

"So first the plaster dissolves partially in contact with the water, as Landrin pointed out in his second principle, and as accepted by Chatelier. Next, some changes take place, whereby, according to Marignac's experiment, the liquid becomes turbid and crystallization begins. Landrin thought evaporation took place as a result of the heat formed by chemical combination, and that then a crystal was formed which started the crystallization through the entire mass. Chatelier showed by experiment that evaporation was not necessary and he argued that by taking up of this water the solubility of the hydrate was decreased, and so, on account of the resulting supersaturation, crystallization ensued.

"The solution of the hydrate in these experiments is certainly saturated, and all that is needed is something to start the crystallization. From a study of saturated solutions in the laboratory, it is well known that if crystals are introduced into such solutions crystallization will result and go on until the salt is crystallized out.

"The effect of heat on gypsum in the burning of plaster, as we have shown, is to remove a certain percentage of water and break up the small masses of the rock into finer and finer particles, microscopic and ultra-microscopic in size. If the heat is not carried too far certain particles through the mass may still possess their crystalline form and so they are true crystals though very small. These minute crystals in the saturated solution would start the process of crystallization. Their growth would cause the turbidity of the solution as noted by Marignac, and would result in the percipitation of small gypsum crystals, thus forming the crystal network which constitutes the set of the plaster.

"If the plaster is unburned the gypsum is not reduced to the proper fineness and uniformity, and so would not permit the crystallization to go on in the way it would in the properly burned plaster. But of more importance, the hydrate represented by plaster of Paris would not be formed.

"If the plaster is overburned, the plaster will be so completely comminuted that no minute crystals would be left to

start the crystallization. Where the plaster is slightly overburned, the crystals are extremely fine and crystallization goes on very slowly and imperfectly."

PROCESSES OF MANUFACTURE.

The processes and machinery used in the manufacture of calcined gypsum products are in general very simple. The different operations involved in the manufacture in Oklahoma are quarrying, crushing, grinding, calcining, screening or classifying, and mixing.

Quarrying.—In Oklahoma all the rock gypsum is obtained from open hillside quarries. The supply of material near the surface is so great that underground methods will probably not be used for years to come. The material is blasted from the face of the ledge in large blocks and broken by means of hammers or mud shots into pieces easily handled by one man. Dynamite is the explosive used. Hand power augers are used to make the holes for the shots. The augers are of two types. The larger auger is on a heavy tripod like that of a steam drill and is operated by a crank. The other form is a simple auger similar to the carpenter's brace and bit, but 6 to 8 feet long. Pressure from the operator's body is applied to a cross bar at the top of the shaft. The broken rock is loaded into wagons or into dump cars on tracks and hauled to the mill or crushing plant. Gypsite is generally scraped up in drag scoops and loaded into wagons or care through a trap. Where the plant is very near the bed, wheeled scrapers are used and the "dirt" hauled directly to the plant.

Crushing.—Gypsite is ready for the kettles with no further treatment but the rock gypsum must be pulverized to a fine flour before calcining. For the first reduction a powerful jaw crusher (fig. 8) or nipper is used.

Fig. 8.—Jaw crusher.

The end of the machine opposite the pulley is of chilled iron. Opposite this is a movable chilled plate of the same pattern. The two are set at an angle so as to form a V-shaped box. The movable plate is moved alternately toward and away from the fixed plate by an arm which is driven by an eccentric on the shaft.

The capacity of the crushers and the power required to operate them vary greatly with the condition of the gypsum, since dry rock is crushed much more rapidly and with less power than wet rock. The following table[48] gives data as to size, capacity, etc., of the different sizes of crushers.

Jaw Crusher.

Size jaw opening in inches	Capacity in tons per hr. Jaws set apart 2 in.	Approx. weight, pounds.	Speed rev.	Pulley, inches.	Horse-power, approx.	List price.
15 by 22	12 to 25	10,000	250	36 by 10½	15	$ 550.00
22 by 28	25 to 40	20,000	230	40 by 12	25	900.00
24 by 34	60 to 70	24,000	230	42 by 15	35	1000.00

The 22 by 28 inch crusher is the one generally used in the gypsum mills. This machine will take pieces of about 50 pounds

[48]This table as well as the similar ones in the following paragraphs, is taken from the catalog of the J. B. Ehrsam & Sons Manufacturing Company, Enterprise, Kansas.

weight and reduce them to pieces about the size of a man hand.

For further reduction a rotary fine crusher or cracker (fi

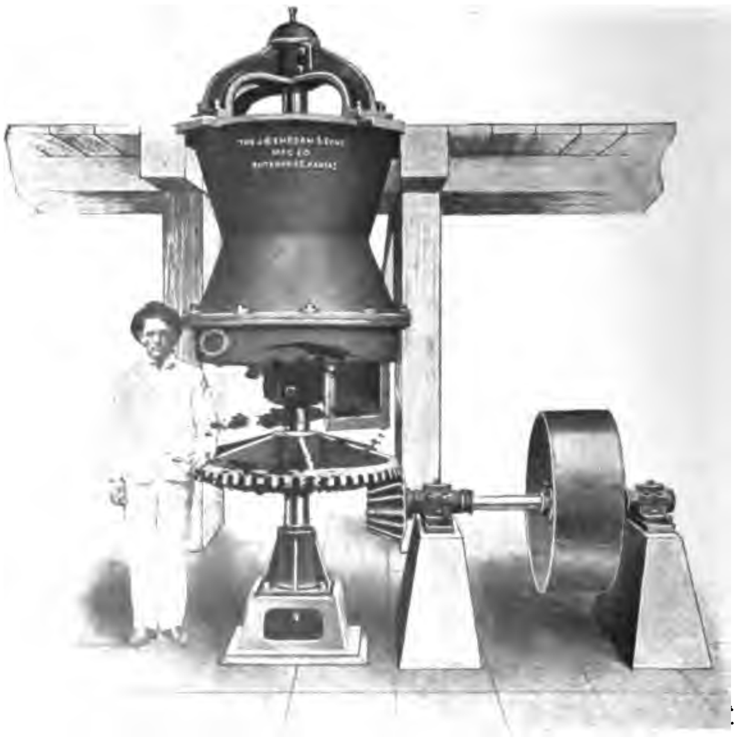
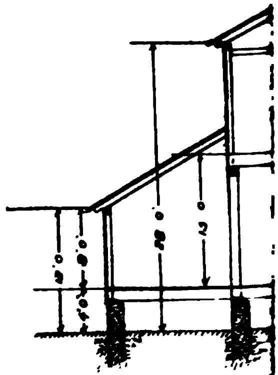


Fig. 9.—Rotary fine crusher or cracker.

9) is used. This machine consists of a conical shell whose inner surface is corrugated. Inside the shell revolves a shaft with a corrugated iron shoe. The crushing action is similar to that of the ordinary coffee mill. The rock is reduced in this mill to pieces a little larger than grains of corn, and in this condition is known as gravel. The crackers are made in different sizes as shown in the following table.



Rotary fine crushers.

No.	Largest size piece will take	Approx. cap., tons per hour	Horse power, approx.	Speed rev.	Pulley, inches.	Approx. weight, pounds.	List price.
1	4 in. Diam.	4 to 8	1 to 3	165	30 by 8	1,600	$150.00
2	6 " "	10 to 20	4 to 6	240	36 by 10	4,200	350.00
3	12 " "	25 to 40	15 to 25	240	36 by 13	10,000	550.00
4	14 " "	30 to 50	20 to 35	240	36 by 15	14,000	700.00

Grinding.—The gravel from the cracker is ground to powder in buhr mills. These mills may be either horizontal (fig. 10)

Fig. 10.—Enterprise horizontal buhr mill.

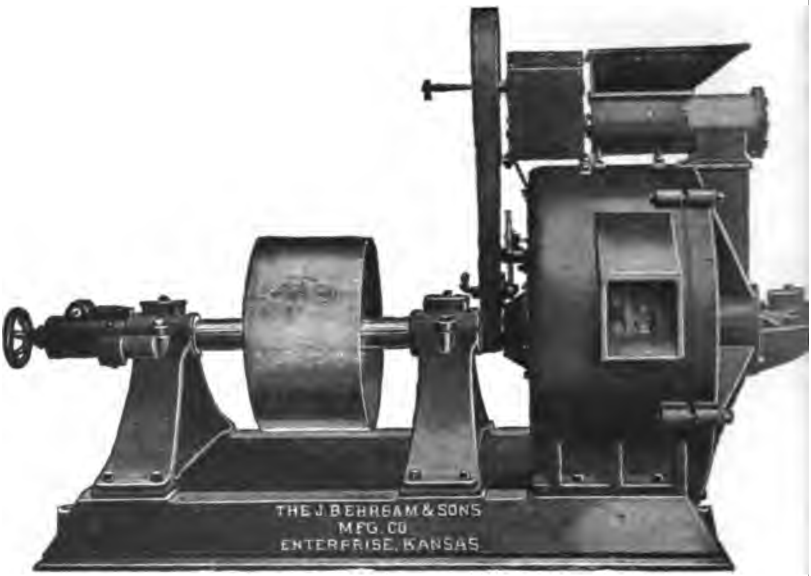


Fig. 11.—Enterprise vertical buhr mill.

or vertical (fig. 11) types. The stones are pebble grit, French buhr stones or rock emery (Sturdevant Mill). The faces of the stones are dressed into radiating furrows and must be redressed when they are ground smooth. An additional set of stones is usually kept on hand so as to save delay in operations while the dressing is done. In most of the mills the stones are mounted so that the faces are automatically drawn apart when the mill is not being fed. The capacity of the buhr mill varies greatly with the condition of the gypsum. Wet gypsum grinds much more slowly and requires more power than dry rock. The capacities and dimensions of the different types of buhr mills are given in the following tables:

Horizontal buhr mills.

Size	Height to top of feeder	FLOOR SPACE		Pulley, inches	Speed	HEIGHTS		PRICES			
		Pulley	Geared			Pulley	Geared	Pebble grit	Solid French	Old quarry French	Emery stones
42 in.	5 ft. 11½ in.	5 ft by 5 ft	8 ft. 5 in. by 5 ft.	30 by 14	400	6400	7000	$400.00	$450.00	$500.00	$600.00
36 in.	5 ft. 6 in.	4½ ft by 4½ ft	8 ft. 4 in. by 6 ft.	24 by 10	450	4500	5000	300.00	350.00	400.00	500.00

Vertical buhr mills.

Size	Length	Width	Height	Pulley, inches	Speed	Approx. weight, pounds.	Horse-power, approx.	Cap. tons per hour.	Prices		
									Pebble grit	French buhr	Rock emery
30 in.	6 ft. 0 in.	3 ft. 6 in.	4 ft. 2 in.	20 by 8	650	3600	10 to 20	1 to 4	$350.00	$375.00	$500.00
36 in.	9 ft. 3 in.	4 ft. 2 in.	5 ft. 9 in.	26 by 14	550	6800	20 to 35	3 to 8	550.00	600.00	750.00

Another machine for fine grinding is the lime disintegrator which consists of two cages revolving one within the other and in opposite directions. The cages have short cross-bars. The gypsum gravel is fed into the middle of the cages and by the motion is thrown out between the bars and is pulverized by the impact of the particles against the bars and against each other. The machine does not clog and has a high capacity, that of the 50-inch disintegrator being 60 to 75 tons in 10 hours. This machine saves the expense of dressing the buhr stones. It is used in some of the Michigan mills but has not been introduced into the Kansas and Oklahoma mills.

Calcining.—The calcining kettles are cylindrical and are built of steel three-eighths of an inch thick. The ordinary sizes are 8 to 10 feet in diameter and 8 feet in depth. A vertical rod passing down through the center of the kettle and driven by a cog wheel at the top, is provided with arms which stir the gypsum and keep it from burning on the bottom of the kettle while it is being calcined. Two or four flues about 1 foot in diameter pass through the kettle horizontally to secure a better distribution of the heat. In 4-flue kettles the flues are arranged in sets of two, a lower and an upper set. The kettles are set like a boiler above a grate and surrounded by a wall about two feet thick built of brick—fire brick on the inside and common brick on the outside. A space is left between the kettle and the wall, and partitions in this space cause the gases from the fire to pass into and through the lower flues, then entirely around the kettle and through the upper flues. The 10-inch kettle with 4 flues has a capacity of about 14 tons of plaster. Plans and sections of a 2-flue kettle and setting are shown in figure 12.

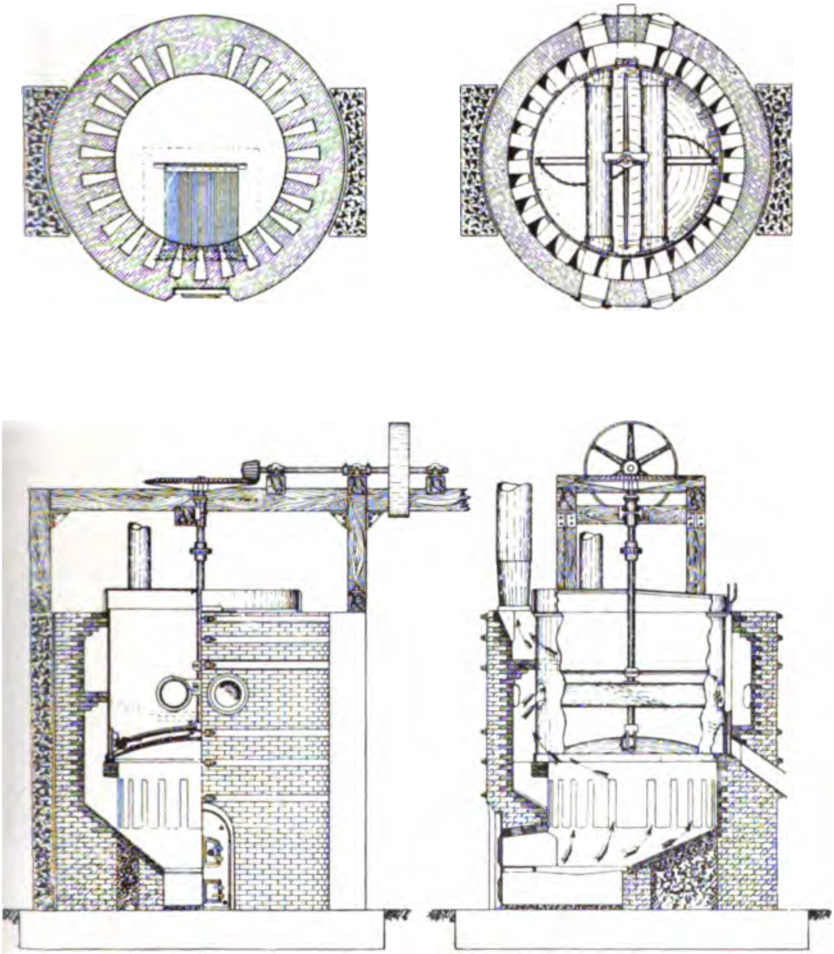


Fig. 12.—Ehrsam's 2-flue calcining kettle, standard setting.

Data concerning dimensions, capacities, and power required for the different sized kettles are given in the following table:

Data for calcining kettles.

Diameter of kettle	6 ft.	8 ft.	8 ft.	10 ft.	12 ft.	14 ft.
Height of kettle	6 ft.	6 ft.	8 ft.	8 ft.	8 ft.	8 ft.
Number of flues	2	2	4	4	4	4
Diameter of flues	12 in.	14 in.	14 in.	16 in.	20 in.	24 in.
Thickness of shell in kettle	¼ in.	¼ in.	¼ in.	⅜ in.	⅜ in.	7-16 in.
Thickness of tubes in kettle	¼ in.	¼ in.	¼ in.	¼ in.	¼ in.	¼ in.
Diameter of smoke stack	14 in.	20 in.	20 in.	24 in.	28 in.	36 in.
Length of smoke stack	40 ft.	48 ft.	48 ft.	48 ft.	48 ft.	48 ft.
Grate surface	2 by.3 ft	3 by 4 ft.	3 by 4 ft.	4 by 5 ft.	4½ by 5ft.	6 by 6 ft.
Diameter of upright shaft	3 3-16 in.	3 15-16in	3 15-16 in.	4 15-16 in.	5 2-16 in.	6⅝ in.
Length of upright shaft, lower section	7 ft. 6 in.	7 ft. 6 in.	9 ft. 10 in.	9 ft. 10 in.	9 ft. 10 in.	9 ft. 10 in.
Length of upright shaft, upper section	3 ft. 6 in.	3 ft. 6 in.	3 ft. 6 in.	4 ft.	4 ft.	4 ft.
Number of kettle bands	3	4	4	6	6	6
Weight of kettle and fixtures	6,000 lbs	12000lbs	13,000 lbs	20,000 lbs	30,000 lbs	46,000 lbs
Number of common brick above floor	10,000	16,000	17,000	23,000	32,000	48,000
Number of fire brick	2,000	4,000	4,800	7,000	10,000	16,000
Capacity per charge (tons)	2 to 3	5 to 6	6'to 7	12 to 14	15 to 18	20 to 25
Power required on ground gpysum under ordinary conditions	8 h. p.	15 h. p.	15 h. p.	25 h. p.	38 h. p.	50 h. p.
Price	$450.00	$650.00	$750.00	$1000.00	$1400.00	$190.00

The gypsite or ground rock is fed slowly into the kettles, 1 to 2 hours being required to fill a 14-ton kettle, depending on the condition of the material. While being filled the kettle is kept at a temperature of about 212°F.

In about one hour after being filled the kettle reaches a temperature of 230°F. and the mass begins to "boil" owing to the expulsion of the water of crystallization. At about 10° higher the mass settles down solid, but at 270°F. begins to boil violently again. At about 350°F. a gate near the bottom of the kettle is opened and the calcined gypsum flows rapidly into the "hot pit" which is built of fire-proof material.

From this pit the material is elevated and screened through bolting cloth or fine wire screens. The portion passing through the screens is conveyed to bins above the mixers, while the coarse material is reground. In the bins retarder and hair or wood fibre are added, the whole passed down through the mixer which has openings at the bottom, through which the plaster is fed into sacks holding 100 pounds each.

In one mill in the State, at Wilson, the Cummer continuous calcining process is used. In this process a rotary kiln (fig. 14) is used in place of the kettles. The rock is crushed to three-fourths inch ring and stored in a bin over the feed spout of the rotary kiln. A mechanical feeder regularly feeds the crushed rock into the kiln. The calciner is provided with a mechanical stoker and special furnace setting to secure perfect combustion. The heated gases from the combustion are drawn by a fan into a large commingling chamber, which extends the entire length of the cylinder. At the same time sufficient air is admitted through registers in the side walls of the commingling chamber and mixed with the heated gases from the furnace to give the temperature best suited to the material.

The cylinder (which is set at an incline and revolves slowly on steel rollers) has a great many hooded openings so arranged that the heated air and gases from the commingling chamber are drawn by a fan through the hoods into the cylinder, in direct contact with the gypsum gravel which enters the machine at the front end. The rock is constantly being cascaded in the cylinder by means of lifting blades.

In the discharge spout is a recording thermometer which registers accurately the temperature of the rock as it comes

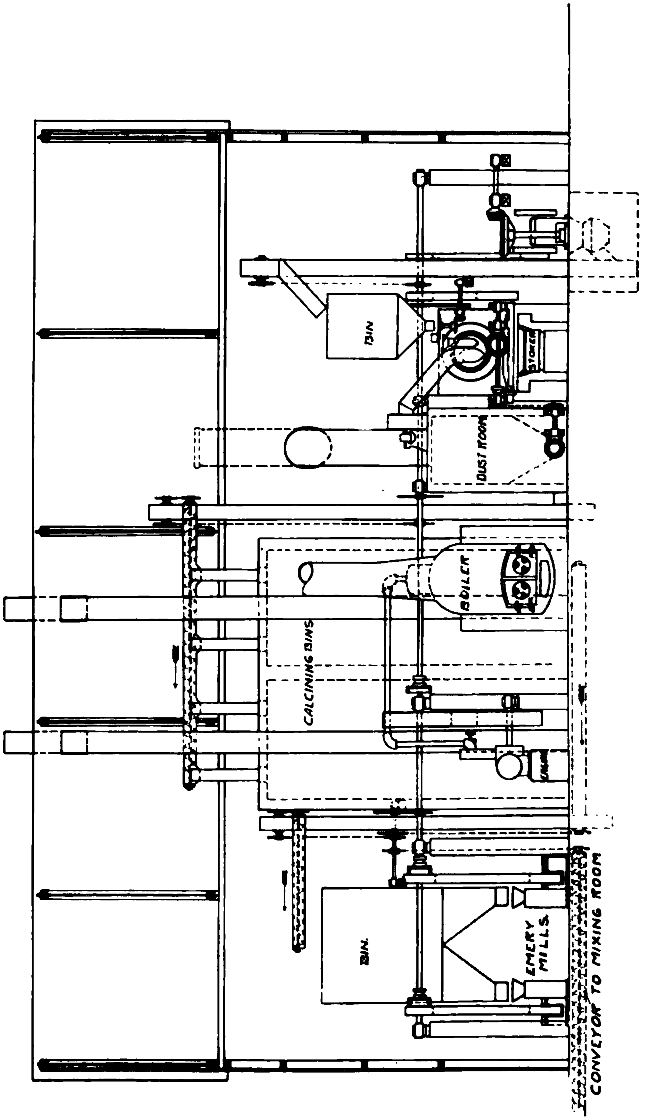
out. The dial of this recording thermometer is so located that the operator can watch it and keep the rotary calciner adjusted so as to give a uniformly heated product. It is claimed that the rock as it is discharged will not vary in temperature more than 10° during a whole day's running. The heated air passes through the cylinder in the opposite direction to that in which the gravel is moving. The data for the rotary kilns are given in the following table:

Approximate capacity, fuel, horse-power and labor for Cummer continuous calcining process for gypsum.

No.	Capacity per 24 hours, tons	Horse power	Coal per day for calcining, pounds	Labor per shift. men.
1.	50	6	3,500	1
2.	100	8	7,000	1
3.	150	10	10,500	1
4.	200	12	14,000	1
5.	250	15	17,500	1
6.	300	20	21,000	1
7.	400	28	28,000	2

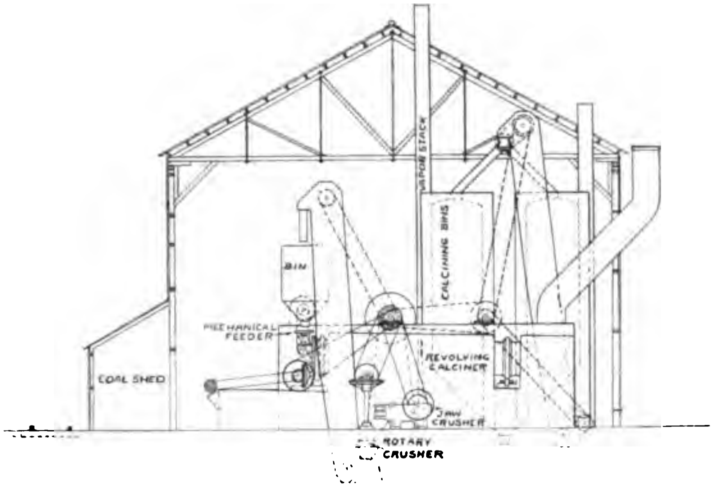
The general arrangement of a mill using this process is shown in figures 15, 16 and 17.

Fig 14.—Cummer rotary calciner.



FRONT ELEVATION.

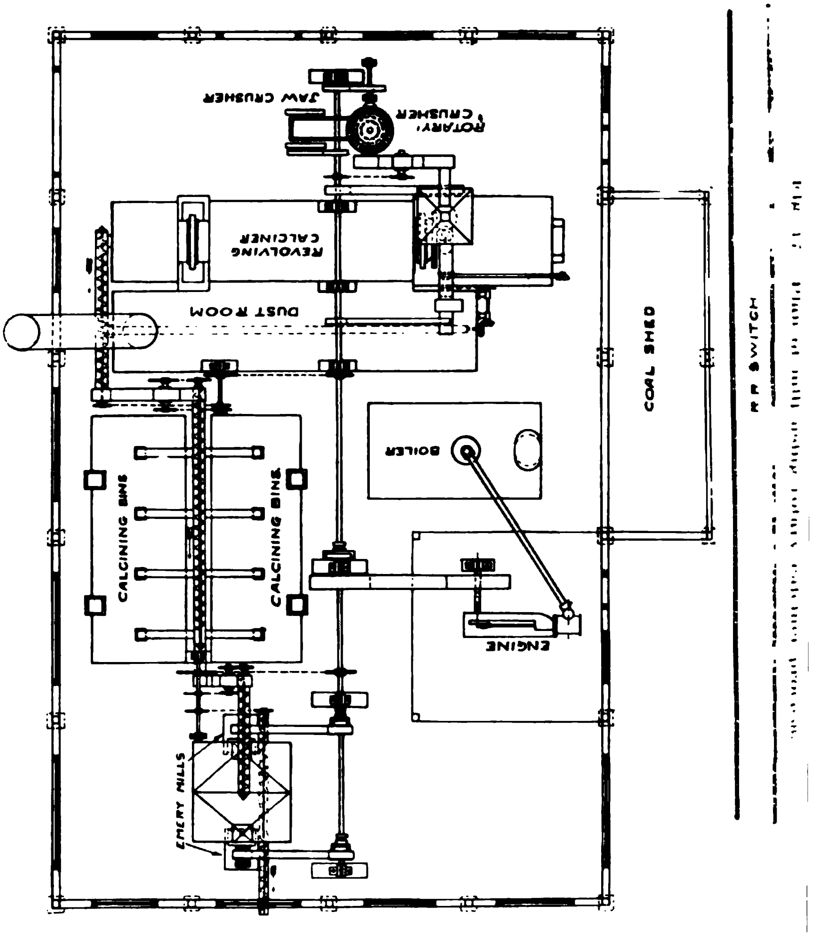
Fig. 15. Front elevation of mill using rotary calciner process.



END ELEVATION.

Fig 16.—End elevation of mill using rotary calciner process.

About 10 minutes is required for the material to pass through the kiln and during its passage it reaches a temperature of 400° to 500°F. It is then elevated to large bins built of brick or of wood lined with brick and allowed to remain 36 hours, during which time the excess heat carried over from the calciner is equally distributed through the material, which is thus uniformly calcined. The fine dust is calcined in the cylinder and is carried out by the current of air into a dust room, where it is collected. This dust is used for the finer grades of plaster, such as dental and molding plaster. The calcined gravel is ground in buhr mills, screened and mixed as in the kettle process. The process is based on the fact that heat in excess of that required for calcination when applied in the presence of moisture does not result in "dead burned" plaster. The gravel is steaming during its stay in the kiln and still contains moisture when placed in the bins. The advantages claimed for the process are two, saving of fuel for calcination due to the continuous process, and the saving in power, since the rotary calciner is said to require less power than kettles of equal capacity and much less power is required for grinding the calcined material from the bins than for grinding raw gypsum as it comes from the quarry. It is claimed that 70 pounds of good coal is required to calcine one ton of plaster in the rotary kiln, while 150 to 200 pounds



are required per ton in the kettles. The power necessary for a rotary calciner of 200 tons capacity per 24 hours is claimed to be 12 horse power, while 3 8-foot kettles, giving somewhat less capacity, require forty or more horse power at least a portion of the time. The only mill in Oklahoma using this process has been in operation but a short time and the plaster has not yet been thoroughly tried out on the market. However, it is reported to be of good quality, and the plaster made by the process in the east is said to be satisfactory.

In Germany[44] the ordinary wall plaster and plaster of Paris are burned in kettles or in continuous rotary kilns similar to those employed in the United States. The kettles are smaller as a rule and do not have the flues. For the finer plasters, especially for the plaster for molds used in the making of porcelain, continuous kilns are used which are similar to the tunnels used for drying bricks in this country. The walls are of brick and are very thick. The gypsum gravel is loaded on pallets or shelves on rack cars which are moved slowly through the tunnels on tracks. In one type of kiln the heat is not applied directly to the gypsum, but the gases from the combustion chamber are led through flues in the wall. In another type of kiln the gypsum in blocks is loaded on to the cars, which are covered with sheet steel, the cover of each car fitting closely with the cover of the cars to the front and rear. The fuel is burned at the middle of the tunnel, so that the gypsum becomes heated as it approaches the middle, is calcined as it passes the fire, and cools as it approaches the exit.

For the calcining of "estrick" gypsum, a slow-setting hard plaster, burned at about 500°C., kilns resembling the ordinary lime kilns are used. Wilder's description of these kilns is as follows:

"Estrick gypsum is calcined in a kiln resembling the ordinary kiln used for burning lime. When possible, the kiln is located near the quarry or mine, and in a hollow or depression, artificial or natural, so that the trucks carrying the rock from the quarry may be run directly to the top of the kiln and there automatically emptied. The kiln will hold about 200 tons at one time, though all of this amount is not subjected to the full furnace heat. The accompanying diagram will best explain its nature. The sketch is made from the side. The fireplace is represented by D, the ashes falling down into E. The gypsum blocks are thrown in at A, and the whole interior filled. The fireplace on its upper side and rear is grated, and the flames and heat pass directly up through A. The hottest part of the kiln is found at B, where a comparatively small amount of gypsum is brought directly in contact with the grates. From time to time the rock which has been exposed to this great

[44]Wilder, Frank A., The gypsum industry of Germany: Iowa Geol. Survey, vol. 12, 1902, pp. 209-220.

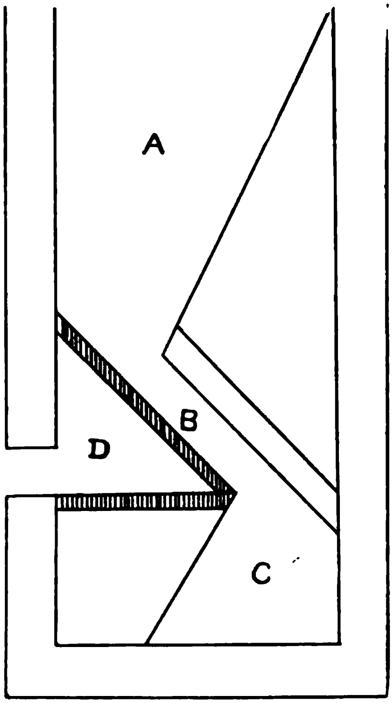


Fig. 18.—Sketch of kiln for burning estrick gypsum (After Wilder).

heat passes on down into C, the cooling chamber. This will take place whenever the rock already calcined and cooled is removed from C and taken to the mill for grinding. The heat in the lower part of A is so intense that nearly complete combustion takes place, and only gases and hot air, without smoke, pass on up through A, and escape at the top. The process is, then, a continuous one, with but slight loss of heat. There is little danger of overheating the gypsum and no attempt to perfectly control the temperature is made."

In France[45] the common type of kiln is similar to the square up-draft brick kilns of the United States. The gypsum is stacked into the kilns with the large blocks in the bottom forming a series of tunnels in which the fuel is burned. Smaller blocks are placed on top, filling the kiln to a depth of about

[45]Grimsley, G. P., The gypsum of Michigan and the plaster industry. Mich. Geol. Survey, vol. 9, Pt. II, 1904, pp. 17-20.

13 feet. The kiln is covered by a shed roof. The kiln is fired until the large blocks are glowing. The material next the fire is overburned and that at the top is underburned, but the mixture of the two ground together is said to give a uniform product of good quality. Another type of kiln is circular with the fire pit in the center and with the arches or tunnels of large gypsum blocks radiating from the pit. The top of the kiln is an arch which has flues to control the draft. In other kilns the gypsum is calcined in retorts. Superheated steam has been used for calcining in both Germany and France.

Screening.—From the hot pit the plaster is conveyed by a screw conveyor to a bucket elevator which carries the plaster to the screens: Both the rotary and shaking types are used, the screen being of fine wire mesh about 40 meshes to the inch. The material passing the screens is conveyed into bins on the second story of the mixing room. For plaster of Paris the material is sacked directly from these bins.

Another machine used for classifying the material is the inertia classifier, which is shown in figure 19. This machine is made in sizes of 3 to 8 tons per hour capacity. It requires from 4 to 12 horse power.

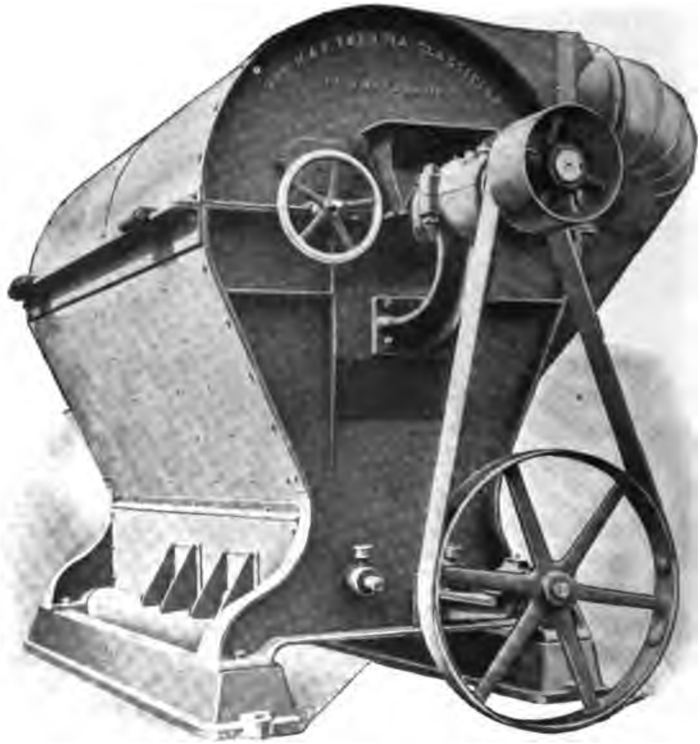


Fig. 19.—Mosher-Ehrsam classifier.

With either method of separation the tailings are conveyed to a regrinding buhr and ground to the requisite fineness.

Mixing.—The mixing machine (fig. 20) consists of a charging hopper, a mixing chamber and a sacking chamber. The charge of plaster is run into the hopper from the bins and the retarder or accelerator and hair or wood fiber, according to the product desired, are added in the proper proportions. By pulling a lever the operator discharges the hopper into the mixing chamber, where it is mixed from 3 to 8 minutes. While this charge is being mixed a second charge is prepared in the hopper so that the operation is continuous. After the charge in the mixing chamber is mixed the operator opens the valves into the sacking chamber by means of the pilot wheel. The mixing chamber has a mixing shaft with two sets of paddles

Fig. 20.—Enterprise noiseless mixer.

so arranged that one set throws the material from outside of the mixing chamber toward the center, at the same time causing the material to travel toward one end of the chamber, while the other set of paddles causes this operation to be reversed. Thus there are counter currents of material constantly commingling, causing a perfect mixture. The sacking chamber is made of seasoned lumber, lined with sheet steel and provided with an agitator for keeping the material from clogging. Convenient sacking spouts are provided and the sackers ordinarily have nothing to do with the operation of the mixer, confining

their energies entirely to filling, weighing, and sewing. The mixer is made in two sizes. No. 1 has a capacity of from 1,000 to 1,500 pounds to the charge. This machine will mix from 40 to 65 tons of material per day of 10 hours and is provided with five sacking spouts. The mixer should run 165 R. P. M. and is provided with 36-in. by 8-in. tight and loose pulleys. The weight of the mixer is 3,800 pounds. The power required depends entirely on the kind of material mixed and will vary from 5 to 15 H. P. The No. 2 mixer is provided with seven sacking spouts and has a capacity from 1,800 to 2,400 pounds to the charge, and a capacity of 80 to 100 tons per day of 10 hours where a good sacking crew is provided. This mixer should run 165 R. P. M. and is provided with 36-in. by 12-in. tight and loose pulleys. It requires from 15 to 30 H. P., depending on the kind of material mixed. The shipping weight is 4,400 pounds. The list price for the No. 1 mixer is $325.00, and for the No. 2 mixer, $400.00.

SUBSTANCES ADDED TO THE PLASTER.

Plaster of Paris sets in a few minutes and consequently cannot be used alone for ordinary work. In order to delay the set sufficiently to permit the material to be mixed and spread on the walls retarders are added. A great many substances, most of them of an organic nature, are or have been, used as retarders. Glue, blood, sugar, gelatin, flour, saw dust, and many other substances and combinations of these with various inorganic salts have been used. The Oklahoma mills use a retarder which is manufactured by the large packing concerns from slaughter house refuse. The amount of retarder added to the plaster depends on the demands of the trade. Ordinarily a plaster which sets in from 2 to 6 hours is demanded, and to provide such a plaster about 4 to 6 pounds of retarder per ton is used.

In plaster for some special purposes, such as dental plaster a very quick set is desired and an accelerator is added. Borax and common salt are commonly used for this purpose.

Hair and wood fibre are added to wall plaster. The hair is purchased in large bales by the mills. The compressed material is passed through a small machine which picks it to pieces so that the hairs are evenly distributed through the plaster

n the mixer. The wood fibre is made from cotton-wood, which s fibred by machines, one type of which is shown in figure 21.

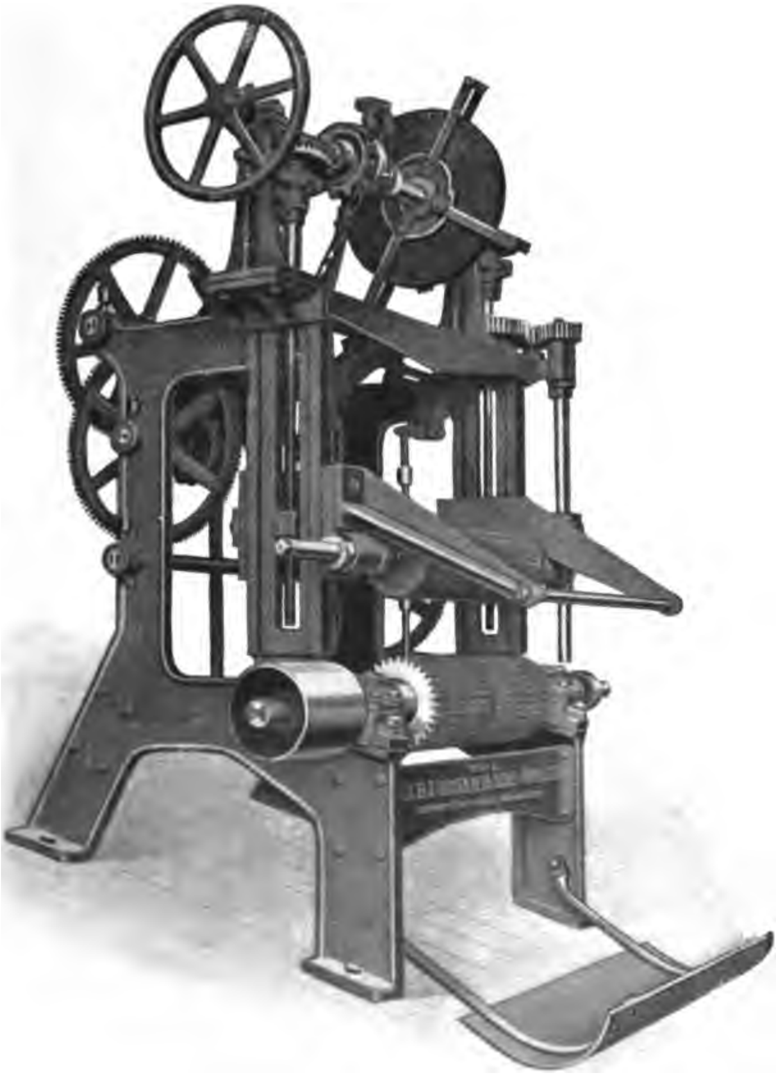


Fig. 21.—Wood-fibre machine.

ARRANGEMENT OF PLASTER MILLS.

While the details of arrangement of the different mills vary considerably the general plans are very similar. In general the crusher is located at one end of the mill and is on the ground, with the cracker in an excavation below it. The rest of the ground floor is occupied by the kettles and hot pit and the sacking and storage rooms. The second floor is occupied by the tops of the kettles and by the buhr mills for grinding and regrinding. The charging hopper for the mixer is also on the second floor. The third story is almost entirely filled with storage bins for the buhrs, kettles, and mixer. In general the crushing and power plants are at one end of the mill, the grinding and calcining departments in the middle part, and the mixing, sacking, and storage rooms at the other end.

The general course of the material is as follows: The crushed gypsum drops from crusher to cracker; the gravel is carried from the cracker by bucket elevator to bins over buhrs, passes through the buhrs and the ground material or flour is carried by bucket elevators to bins over calcining kettles; through these into hot pits, then by screw conveyor and bucket or other elevators to screen or classifiers; the fines from the classifier pass to bin over mixer, and the tailings to regrinding buhrs and then to bin over mixer, all go through mixer into sacks. The arrangement of a 2 10-foot kettle mill adapted for rock gypsum is shown in figure 13.

Mills using gypsite alone have only the regrinding buhrs of the crushing or grinding machines and the material is sent directly from the bed or from drying sheds into the kettles.

COST OF BUILDING AND EQUIPPING PLASTER MILLS.

The cost of building and equipping a plaster mill will vary greatly with the type and capacity of the mill and in less degree with the location with respect to transportation, to availability of building supplies, and to labor conditions. It is, therefore, impossible to give estimates which will fit exactly any particular case. The following estimates, however, are sufficiently accurate under ordinary conditions to give an approximate idea of the cost of different types of kettle mills. The estimates, except for the mill shown in figure 13, are taken

from Jennison's report on the Gypsums of the Maritime Provinces (Canada). The specifications are for the machinery of the J. B. Ehrsam and Sons Mfg. Co. of Enterprise, Kansas, who have equipped most of the mills in Oklahoma and who have furnished estimates for the mill shown in figure 13.

Estimate of cost of plaster mill, having a capacity of 25 tons in 24 hours, wood construction.

Machinery consists of the following:

One 6 by 6 ft. calcining kettle.

One 20 in. Ehrsam vertical green-grinding buhr mill.

One 20 in. Ehrsam vertical regrinding buhr mill.

One 20 in. Ehrsam rotary crusher.

One special Enterprise noiseless mixer.

Necessary elevators, conveyors, power transmission, and kettle-pit feeders for the automatic handling of material from crusher to mixer.

Power required to run plant, 60 H. P.

Cost of special machinery	$1,120
Cost of elevators, conveyors, power transmission and kettle pit feeders	834
Approximate cost of building and bins complete, including masonry and cost of erection	4,000
Approximate cost of power plant, consisting of one simple slide valve engine, one tubular boiler, and connections	800
Approximate cost of plaster mill, complete	$6,754

Estimate of cost of plaster mill having capacity of 100 tons in 24 hours, wood construction.

Machinery consists of the following:

Two 8 by 8 ft. calcining kettles.

Two 36 in. Ehrsam vertical green-grinding buhr mills.

One 36 in. Ehrsam vertical regrinding buhr mill.

One 15 by 22 in. Ehrsam jaw crusher.

One 20 in. Ehrsam rotary crusher.

One No. 2 Enterprise noiseless mixer.

One Ehrsam hair picker.

One 21 in. by 14 ft. vibratory screen.

Necessary elevators, conveyors, etc.

Power required to run plant, 150 H. P.

Cost of special machinery............................$ 5,115

Cost of elevators, conveyors, power transmission, bin and kettle-pit feeders........................... 2,385

Approximate cost of bins and building complete, including masonry and cost of erection................. 14,00

Approximate cost of power plant, consisting of one 16 in. by 36 in. Corliss engine, one 72 in. by 18 ft. high pressure boiler, and connections................. 3,00

Approximate cost of plaster mill complete.............$24,50

Estimate cost of plaster mill having a capacity of 200 tons in 24 hours (see fig. 21). Steel construction and fireproof throughout.

Machinery consists of the following:

Two 8 by 10 ft. calcining kettles.

Five 42 in. horizontal buhr mills.

Three Mosher-Ehrsam classifiers.

One 22 in. by 28 in. Ehrsam jaw crusher.

Three No. 2 Enterprise mixers.

Two vibratory screens, 21 in. by 8 ft.

Elevators, conveyors, power transmission, etc.

Power required to run plant, 300 H. P.

Cost of special machinery	$12,000
Cost of steel building and bins complete	20,000
Cost of concrete foundation and brick work for setting machinery	3,000
Cost of millwright labor, superintendence and setting of machinery	3,000
Approximate cost of power plant, consisting of two 72 in. by 18 in. high pressure boilers, one compound 14 by 28 by 36 in. high speed Corliss engine, pumps, condenser, cooling tower, fixtures, piping and erection	$12,000
Approximate cost of plaster mill complete	$50,000

A similar mill, but with a capacity of 300 tons per 24 hours, requires three 10 by 8 ft. kettles and additional grinding and mixing machinery. The power required is 400 H. P. Such a plant, including the power plant, costs approximately $65,000.

COSTS OF PLASTER MANUFACTURE.

Eckel[46] gives the following table as showing in his opinion the maximum, average, and minimum costs of plaster by the kettle process, in the United States. Fixed charges such as office expenses, interest on investment, deterioration of equipment, and expenses of sales force are not included in these estimates.

	Max.	Min.	Average
Mining or quarrying 2400 pounds gypsum	$0.72	$0.12	$0.30
Power fuel at mill, 75 to 125 pounds coal	0.19	0.05	0.10
Kiln fuel at mill, 225 pounds to 325 pounds coal	0.49	0.15	0.30
Labor at mill	0.50	0.30	0.40
Total cost per ton of plaster at mill	$1.90	$0.62	$1.10

Grimsley[47] estimated the cost of manufacture in the Kansas mills at $1.60 per ton, exclusive of office force and sales agents.

The actual cost in Oklahoma will vary considerably with the local conditions at each mill. The following figures show the cost for three different months at one mill where conditions are probably about an average of those in the State. Owing to the fact that the mill was not running at full capacity these

[46]Eckel, E. C., Cements, limes, and plasters: 1909, p. 32.
[47]Grimsley, G. P., Mineral industry, vol. 7, 1898, p. 392.

costs are rather high, especially for the third month, during which time the mill was run at about half capacity:

	1st mo.	2nd mo.	3rd mo.
Cost of getting raw material to mill	$0.41	$0.40	$0.5[illegible]
Fuel for power and calcining	0.27	0.31	0.33
Labor in mill	1.02	0.98	1.24
Sundries (repair, retarder, twine, fibre, etc.)	0.28	.21	.23
Total cost per ton plaster at mill	$2.08	$1.90	$2.[illegible]

When the items of interest on investment, depreciation of machinery and buildings, and cost of the executive, office, and sales departments are considered, it is apparent that the real value of gypsum products manufactured from rock gypsum by the kettle process is considerably in excess of $2.00 per ton at the mill and, in Oklahoma at least, will be normally nearer $3.00 than $2.00. The products from gypsite can be manufactured for less than this sum because the material can be delivered at the mill much more cheaply than the rock gypsum and does not require crushing or grinding before going to the kettles.

Figures of costs of manufacture by the rotary kiln process are not at hand. Eckel[48] gives the following estimates:

	Max.	Min.
Mining or quarrying 2400 pounds gypsum	$0.72	$0.12
Power fuel at mill, 50 to 89 pounds coal	0.12	0.04
Kiln fuel at mill, 150 to 200 pounds coal	0.31	0.1[illegible]
Labor at mill	0.30	0.[illegible]
Total	$1.45	$0.4[illegible]

In the writer's opinion these estimates are rather low, especially as no account is taken for retarder, hair, wood fibre, or other sundries.

DESCRIPTION OF OKLAHOMA PLASTER MILLS

At present there are 12 plaster mills in the State, located as follows: 2 at Watonga, and 1 each at Bickford, Okeene, Southard, Wilson, Ferguson, Okarche, Alva, Rush Springs, Eldorado, and McAlester. In the following paragraphs very brief descriptions of these mills, their locations, and equipments are given. The quarries are described under the different counties in Chapter V.

[48]Loc. cit.

The United States Gypsum Company has three mills in ıe State, one each at Okarche, Southard, and Eldorado. The *karche* mill is the oldest in Oklahoma. It is located in northestern Canadian County, 5 miles south and 2 west of Okarche, ; the end of a spur built from the Chicago, Rock Island & acific Railway to the east. The mill is a frame building and ıe equipment consists of a 90 H. P. engine, crusher and :acker, 8 buhr stones, two 8-foot kettles, two mixers, and the sual elevating and conveying machinery. The mill was located

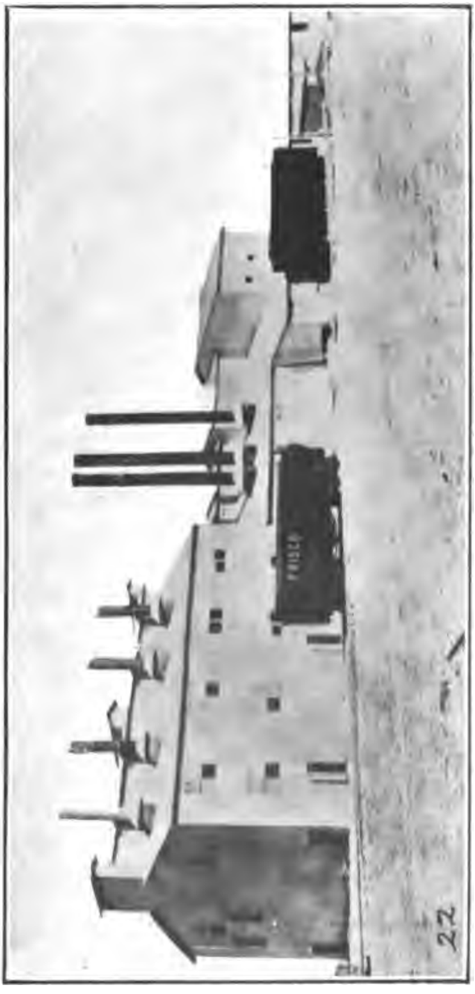


Fig. 22.—United States Gypsum Company's mill at Eldorado.

on account of some gypsite beds but these were exhausted and for some time only rock gypsum from a quarry about one-fourth mile southwest of the mill has been used. The mill was closed down when the company made the purchase at Southard and it will probably not be reopened unless there is a great improvement in business conditions. The *Southard* mill is located southeast of the village of that name in northwestern Blaine County. Transportation is afforded by the Arkansas City and Vernon branch of the St. Louis & San Francisco Railroad. The mill is a large frame building with a large storage room. The equipment consists of a 250 H. P. engine, crusher and cracker, 8 buhr mills, three 10-foot kettles, 2 mixers, elevators and conveyors. All the milling machinery is of Ehrsam make. Both gypsite and rock gypsum are used. This property belonged to the Independence Gypsum Company of Enid, Oklahoma, until the autumn of 1912, when it was sold to the United States Gypsum Company. The products of the Independence Gypsum Company were known under the trade name of "Golden Seal." The *Eldorado* mill is situated just north of the town of Eldorado in Jackson County. This mill is shown in figure 22. The mill has a 150 H. P. engine, four 10-foot kettles, 2 mixers, and the ordinary elevating and conveying machinery.

The *Oriental Plaster Company* of Wichita, Kansas, at present leases two mills in Oklahoma. These are the mill of the Monarch Plaster Company at Watonga, and that of the Southwest Cement Plaster Company at Okeene. The *Monarch* mill is one-half mile north of Watonga on the Chicago, Rock Island & Pacific Railway. The mill covers a very small area in proportion to its capacity. The milling equipment consists of crusher and cracker, 2 French buhr mills, two 10-foot kettles, 1 mixer, elevators, and conveyors. Power is furnished by a 120 H. P. Bates-Corliss engine. The mill has its own lighting system with current furnished by a small dynamo. The rock and gypsite are obtained from the company's land about 7 miles northwest of Watonga. The *Southwest* mill is located at the east side of the town of Okeene, on the Arkansas City and Vernon branch of the St. Louis & San Francisco Railroad. The equipment at the mill consists of buhr mills, two 10-foot kettles, wood fibre machine, and 1 mixer. Power is furnished by a 125 H. P. Fisher-Corliss engine. The crushing plant is located at the company's quarry, which is on the same railroad, 7 miles

est and 2 south of Okeene. Both rock gypsum and gypsite re used.

The *American Cement Plaster Company* of Lawrence, ansas, operates a mill at Watonga, on the Chicago, Rock Island Pacific Railway. The materials, rock and gypsite, are obained from the company's land about 7 miles northwest of Vatonga, and are hauled in gondola cars by the railway. The rushing plant is at the quarry and consists of a crusher and

Fig. 23.—Portion of mill and cement tile storage yard of the American Cement Plaster Company at Watonga.

cracker of the ordinary type. Power is furnished by a 40 H. P. Fairbanks-Morse internal combustion engine that uses solar oil as fuel. A portion of the quarry is shown in figure 56. The mill has a large storage house arranged so that the cars of gypsite or crushed rock may be dumped from a trestle. A screw conveyor in a tunnel extends the entire length of the gypsite storage room and the material can be conveyed direct to the kettles. When the plant was visited the "gravel" had to be shoveled into a bin for a bucket elevator, but it was planned to tunnel this room and put in a screw conveyor. The power is furnished by a 150 H. P. Atlas engine. Slack coal is used for fuel in calcining and is burned with a forced draft. The mill is equipped with the usual crushing, grinding, elevating, and conveying machinery. The capacity of the plant is 175 tons per 24 hours, but it can be crowded to 225 tons if conditions are favorable. A part of the plaster is used in the manufacture of partition blocks. A view of a portion of the mill and of the block storage yard is shown in figure 23.

The mill of the *Roman Nose Gypsum Company* is located at Bickford, about 8 miles north of Watonga on the Chicago, Rock Island & Pacific Railway. The mill is at the foot of the line of hills which are capped by the gypsums of the Blaine formation and only a very short haul by wagon is necessary to transport the rock from the hillside quarries to the plant. Gypsite is obtained a short distance to the south. The mill and its surroundings are shown in figure 52 in Chapter V. The power is furnished by a Loomis-Bettibone gas producer and a Weber 250 H. P. producer-gas engine. The crushing and grinding equipment consists of a jaw crusher, rotary fine crusher, and buhrs for fine grinding. Three 8-foot kettles are used for calcining, and 2 Broughton mixers for mixing.

It is planned to use a large share of the product in the manufacture of partition blocks. A large building has been erected for this purpose. The blocks are to be made by a continuous process, for which patents are held by the company. An endless revolving apron, carrying brass frames or moulds with collapsible metal cores, passes under the mixing vats. The plaster is mixed with water and poured into the moulds as the latter pass slowly beneath the discharge end of the vats. The table is sufficiently long to permit the plaster to set in the moulds by the time they reach the end. Here the cores

re removed and are returned to the upper end of the table y a conveyor belt, which carries them through an oil bath o that they are ready for use again. The blocks are hauled rom the discharge end of the table on wheelbarrows and stacked n storage yards.

The *Rubey Stucco-Plaster* mill is situated in a canyon in he gypsum hills near the head of Salt Creek about 4 miles vest of Ferguson. The mill is at the foot of a steep bluff apped by Medicine Lodge gypsum. The rock was quarried nd let down to the mill on cars operated by a gravity system. A double track was used and the loaded car going down pulled he empty one up the inclline. The rope connecting the two ars passed over a wheel at the top of the incline. The speed f the cars was regulated by a brake on the wheel. The mill as two 6-foot kettles with the usual crushing, grinding, and nixing machinery. The location of this plant is very unfor- unate, since the coal for fuel must be hauled from Ferguson, a distance of over 4 miles, while the finished plaster must be hauled the same distance. The mill has not been operated for several years and it is difficult to see how it can be operated successfully in view of the keen competition between mills more favorably located in regard to transportation.

The Oklahoma Plaster Company has its mill at Alva, in Woods County, on the Chicago, Rock & Pacific and the Atchison, Topeka & Santa Fe railways. The equipment consists of two

Fig. 24.—Plant of Oklahoma Plaster Company at Alva.

10-foot kettles with the corresponding crushing, grinding, and mixing machinery. The main building is a large frame structure and the power plant is housed in a separate brick building. A view of the plant is shown in figure 24. The raw material is a coarsely selenitic gypsum obtained from a quarry between Quinlan and Belva in Woodward County.

The only mill in Oklahoma using the continuous calciner process is that of the *Oklahoma Gypsum Company*, located at Wilson (postoffice, Homestead) in northwestern Blaine County, on the Arkansas City and Vernon branch of the St. Louis and San Francisco Railroad. The company holds a large acreage of land which is underlain by the Blaine gypsums. The quarry is described in Chapter V. The equipment consists of an Ehrsam jaw crusher and rotary fine crusher, a Cummer rotary calciner with automatic stoker, dust room, and calcining bin, 2 Sturtevant rock emery buhrs, an Enterprise mixer, and the requisite elevating and conveying machinery and storage bins. Power is furnished by a 300 H. P. Webster & Company engine. A view of this mill and a portion of the quarry is shown in

Fig. 25.—Mill and quarry of Oklahoma Gypsum Company at Wilson.

figure 25. The mill is a new one and has been in operation only since early in 1913.

The *Acme Cement Plaster Company* has a new mill located about 4 miles west of Rush Springs in Grady County, at the end of spur track from the Chicago, Rock Island & Pacific Railway. This company does not permit their mills to be visited and no information concerning the mill could be obtained other than that the mill is a fireproof structure of steel and concrete, and that it probably does not differ materially in equipment from the other mills of the State. Gypsite alone is used as a raw material.

The *Elastic Pulp Plaster Company* has a small mill at McAlester in the eastern part of the State. The location was probably chosen on account of the nearness of fuel, since McAlester is in the heart of the coal fields. Rock gypsum is shipped from different quarries in the western part of the State. The mill is a small one, having only one kettle.

CONDITION OF THE GYPSUM INDUSTRY IN OKLAHOMA.

Although the supply of gypsum in Oklahoma is inexhaustible and is easily accessible, the condition of the industry during the past few years has not been satisfactory. This is due to several factors, the principal one being the location of the gypsum area with respect to fuel and market.

The area is at considerable distance from any source of fuel. All the plants in the State, except the one at Eldorado, use coal shipped in from the McAlester field in the southeastern part of Oklahoma or from the Arkansas or the Colorado coal fields. The cost of coal at the mill varies from $2.80 to $4.00 per ton. The cost of coal is much higher than in many other regions at the same distance from productive coal fields. This is due to the geologic conditions under which the Oklahoma coals are found which make mining more expensive than in the eastern and central states. The mining methods in use during the past few years are extremely wasteful and these have also operated to make the cost of coal unduly high. Gas from the northeastern Oklahoma fields has been piped as far as Oklahoma City but has not been brought into the gypsum area and at present it does not appear as if it would be. The newly discovered gas field in southeastern Stephens County may make it possible to use gas for fuel in the extreme southeastern portion of the gypsum area, but the geologic conditions

over the greater part of the gypsum area are such as to render the discovery of any oil or gas extremely improbable.

The distance of the Oklahoma mills to the large trade centers and the competition of mills more favorably located also work a hardship on the Oklahoma producers. The far eastern markets can scarcely be entered by the Oklahoma products in competition with those of New York, Ohio, and Virginia; the markets of north central States, including those of Chicago, St. Louis, and Kansas City, are in closer touch with the gypsum supplies of Ohio, Michigan, Iowa, and Kansas than with those of Oklahoma; to the south the Oklahoma products come into direct competition with those of the Texas mills; to the west there are no large markets until the Pacific coast is reached and these are supplied by the mills in Nevada, Utah, and California. To the northwest the mills of Wyoming and Montana are more than able to supply the local markets. Thus, the Oklahoma mills are in a large measure confined to the home markets, or when they enter the larger markets must compete with mills which have a great advantage over them in cost of transportation and, in many cases, a further advantage in the matter of cheaper fuel.

For a few years following 1900 the local markets were very active and the mills established at that time made large production with considerable profit. This encouraged the building of other mills until by 1910 all the mills now in the State, with one exception, had been built. Just about this time the period of great building activity following Statehood suffered a cessation due to a number of causes. As a result of the large number of mills built and the lessened market very few mills have been operated to capacity during the past 3 years and some of them have been idle a greater part of the time. The greater part of the production during this time has been sold at prices so low as to prevent a reasonable profit being made by the manufacturers.

All things considered, it appears to the writer, in spite of the abundant supply of raw material, conditions at present are not favorable for further development of the gypsum industry of the State. Any steps toward the establishment of additional mills should certainly be considered very carefully, especially in regard to available markets for the manufactured

products. The increasing use of the gypsum plasters will tend to better this condition in a few years and the development of new uses for gypsum may produce a marked change for the better at any time.

CHAPTER III.

GYPSUM PRODUCTS AND THEIR USES.

INTRODUCTION.

The products of gypsum may be divided into two general classes, the raw and the calcined products. Of these the calcined are much more important at present, although in times past the amount of gypsum used in the raw state in this country was much greater than that used in the calcined form.

USES OF GYPSUM IN THE RAW STATE.

The principal uses of gypsum in the raw condition are as fertilizer or land plaster, as a retarder for Portland cement, in paints, as an adulterant, and for several minor uses.

Use of gypsum as fertilizer or land plaster.—The use of gypsum as a fertilizer has been known from early times. For this purpose the rock is ground to a fine powder and spread evenly over the land at the rate of about 200 pounds to the acre. The fertilizing action is very pronounced with some soils and some crops, but is absent in other cases. The crops most benefited are clover and other leguminous crops. The continued use of land plaster is known to have a deleterious effect on soils and they finally fail to respond to additional application of the gypsum. This fact has given rise to the old saying that "land plaster makes rich fathers but poor sons."

Many theories have been used to account for the fertilizing action of gypsum. However, it is generally accepted at present that gypsum functions very slightly if at all as a plant food. Its action is believed to be that of decomposing insoluble compounds, such as feldspars and micas in the soil and converting their food elements, especially the potash, into soluble forms so that they can be readily utilized by the plants. This action

would account for the final impoverishment of the soil by repeated applications of land plaster. Gypsum has also a slightly beneficial action in rendering the soil flocculent or granular. Probably the only case where the direct application of gypsum to soil would have any permanently good effect is on soil deficient in soluble plant food but with considerable quantities in the insoluble form. An application of gypsum would probably make it possible to secure a good crop of clover or beans. If all or a part of this crop should be plowed under and the land left fallow and later treated with barn-yard manure, a sufficient supply of food element would be supplied to render the land productive of most of the common farm crops. Such land, however, would require considerable mulching and manuring to keep it in good cropping condition.

The use of gypsum upon manure in the stable or heap is undoubtedly of great benefit. For this purpose the rock is ground to powder and this powder is scattered over the litter or bedding in the stables or pen. Three or four pounds per animal per day are used. The gypsum unites with the nitrogen of the manure to form ammonium sulphate, which is not given off into the air and which is not readily washed from the manure in the heaps by rains, but is still easily available as plant food. The gypsum also seems to cause the potash and phosphates to be retained in the manure. When used in this way, gypsum seems to have no bad effect in the soil as it is probably converted to the lime carbonate in the manure.

Use of gypsum in Portland cement[49].—Pure Portland cement sets in a few minutes and consequently requires the addition of some substance to act as a retarder so that the cement can be manipulated before it sets. Gypsum in some form is almost universally used for this purpose. The gypsum may be used in the raw state or as plaster of Paris. The retarding effect is due to the sulphuric anhydride and consequently a less quantity of plaster of Paris than of raw gypsum is required to produce the same result. However, the cost of the raw gypsum is only about one-half that of the plaster so that the raw material is used in practically all the mills. The raw gypsum is added to the cement clinker before grinding. When plaster of Paris is used, it is added to the ground cement. The

[49] Eckel, E. C., Limes, cements, and plasters: pp. 534-537.

amount of gypsum used varies with the composition of the cement and the retardation desired. Ordinarily 1½ to 2 per cent of gypsum is added. This amount gives the maximum retarding effect with cements of ordinary composition and also the maximum increase of tensile strength. The initial set is usually retarded 1 to 2 hours and the final set 4 to 6 hours. Gypsum in large amounts accelerates the set and weakens the cement. The total quantity of gypsum used in Portland cement is considerable. According to the United States Geological Survey the production of Portland cement in the United States for 1911 was practically 15,000,000 short tons. Taking 2 per cent as the average percentage of gypsum used this would give 300,000 tons as an approximation for the amount used in this way.

Gypsum as a basis for Portland cement.—It has been suggested several times that gypsum could be used as the source of the calcareous element of Portland cement and that the sulphur trioxide driven off could be used for the manufacture of sulphuric acid. Patents have been issued for processes of this sort. However, no commercial attempts to apply the process have been made and there are probably grave difficulties in the way of its application. It is doubtful whether the sulphur trioxide could be completely driven off by any practical method; the value of gypsum for other purposes makes it less available than limestone for use in cement manufacture; and the amount of sulphuric acid produced by a large mill would be so great that it is doubtful whether a market could be found for it under present conditions. The distance of the Oklahoma gypsum deposits from the fuel supply and the absence of clays suitable for Portland cement near the deposits are other factors which seem to render such utilization impossible in this State.

Gypsum as a basis for paints.—Gypsum is used as a basis for paint by a company at Fort Dodge, Iowa, and is reported[56] to give good results. The gypsum is used in the raw form. It is ground much finer than when used for plaster.

Minor uses of raw gypsum.—Rock gypsum in the pure white form known as alabaster has been used for centuries

[56]Wilder, Frank A., Geology of Webster County: Iowa Geol. Survey, vol. 12, 1902, pp. 158-159.

for carved ornaments and interior decorations, especially in churches and cathedrals in Europe. Ground white gypsum under the name of "terra alba" has been used extensively as an adulterant for food stuffs, white lead, and drugs. Gypsum is used in a small way as a drug, in chemical work, as a paper filler, as a brewing salt, and in a number of other ways.

USES OF CALCINED GYPSUM.

Classes of calcined gypsum products.—The following classification by Eckel[51] gives the principal classes of the calcined gypsum products.

[51] Eckel, E. C., Cements, limes, and plasters: p. 32.

Classification of gypsum plasters.

A. Produced by the incomplete dehydration of gypsum, the calcination being carried on at a temperature not exceeding 400°F.

1. Produced by the calcination of pure gypsum, no foreign material being added either during or after calcination—Plaster of Paris.

2. Produced by the calcination of a gypsum containing certain natural impurities, or by the addition to a calcined pure gypsum of certain materials which serve to retard the set of the product.—Cement Plaster.

B. Produced by complete dehydration of gypsum, the calcination being carried on at temperatures exceeding 400°F.

3. Produced by the calcination of a pure gypsum.—Flooring Plaster.

4. Produced by the calcination, at a red heat or over, of gypsum to which certain substances (usually alum or borax) have been added—Hard-finish Plaster.

Besides the names given in this classification a number of others are used in the trade. Plaster of Paris is known as moulding plaster or white finish. Dental plaster is a very white, finely ground plaster of Paris. The name stucco is usually applied to plaster of Paris made from impure gypsum or a mixture of gypsum and gypsite. The cement plasters are distinguished by the addition of hair fiber and retarder. Wood

fiber plaster has wood fiber, usually cottonwood, instead of hair. Keene's cement, Parian cement, and a large number of other special cements belong to the class of hard-finish plasters.

Uses of plaster of Paris.—Plaster of Paris is used quite extensively as a white finish coat for walls. Large quantities are used in the making of moulds for pottery and stoneware. The moulds are usually made in two pieces. These are fastened together and the clay is placed in the mould and pressed into it by hand. When the object is partially dry the mould is removed. Plaster of Paris moulds are especially suited for this purpose on account of the rapidity with which they absorb water from the clay.

Casts of statues and other art objects, and of relief maps and models for various sorts of scientific purposes are made of plaster of Paris. A model of the object desired is made of clay or some other plastic material. A negative of plaster is made by pouring the plaster mixed with water over the object. which is placed in a suitable frame. When the negative has set it is removed from the object and the surface coated with shellac or some other non-absorbent material. Then by pouring plaster on the negative and allowing it to set a copy of the original is obtained. The coating of shellac over the negative prevents the plaster of the cast from sticking to that of the negative. Any number of casts may be made from one negative. Casts of statues and other decorative objects made from flooring plaster ("Estrick" gypsum) are used extensively in building in Germany. When properly treated they are sufficiently resistant for outside use.

The plate glass companies use large quantities of plaster for imbedding plate glass on the polishing tables. A very fine grained plaster free from sand is necessary for this purpose.

Dental plaster is a very pure, extremely fine-grained plaster of Paris. An accelerator, usually common salt, is added to hasten the set. This plaster is used by dentists in taking impressions for artificial teeth.

Hard wall plasters.—By far the most important use of gypsum is in the manufacture of hard wall plasters. As has already been noted these are made in several forms. The gray plasters are those made of gypsite or a mixture of gypsite and

rock, while the white plasters are made of pure rock. A pinkish tinge is sometimes given to the white plasters by mixing with the rock a small amount of red clay which is associated with it. The cement plasters are those which have hair fibre but no sand or wood fibre mixed with the calcined gypsum. The plaster with no fibre or sand is sometimes known as "stucco," but this term is used in several different ways. Prepared plasters are mixed with wood fibre or hair, and sometimes with sand. The wood-fibre plaster can be used without sand, but may be mixed with sand if desired by the trade. Both the hair and wood fibre plasters are mixed with the proper proportion of sand at the mill if desired, but they are usually sold without sand.

In the past few years the use of gypsum plasters has increased very rapidly in spite of their cost being somewhat higher than that of lime plaster. The advantages of the gypsum over the lime plaster may be briefly enumerated as follows:

It is much harder and has a much higher tensile strength than the lime plaster. These qualities give much stronger walls and prevent the cracking and loosening from walls or ceilings so common with lime plasters. Its hardness gives it a smooth, hard surface, well adapted for receiving decorative work. Rats and mice cannot penetrate it. It is not injured by water and will not fall from ceilings if wet by leaking of roofs or water pipes. It requires only one-third the water needed for lime plaster and lessens the danger of shrinking or warping of the wood work. It dries out very rapidly and the plasterers can be followed by the carpenters without loss of time. The second and third coats, if these be desired, can be applied much sooner on gypsum than on lime plasters and this effects a great shortening of the time required to plaster the building. It is a much better insulator for heat and sound than lime plaster. In working properties it is fully equal if not superior to lime plaster. The hard wall plaster works equally well on wood lath, metal lath, plaster board or block, brick, or concrete walls.

The methods of applying gypsum are in general the same as for lime plaster, but a few points should be noted. The gypsum plaster begins to set in 2 or 3 hours and the batches mixed should not be larger than can be used in that time. All old plaster should be removed from the mortar bed and from

all tools since this old plaster causes the new batch to set more rapidly than it should. The plaster on the wall should be kept moist until it has had time to set. Too rapid drying produces checking and soft spots in the plaster. The soft spots may usually be remedied by moistening them several times with water.

Plaster wall board, studding, and partition block, or gypsum tile.—These materials are simply applications of the hard wall plasters. The Sackett plaster board of the United States Gypsum Company is made in sheets consisting of alternate layers of felt and gypsum plaster, 4 layers of felt and 3 of plaster. The standard size of the sheets is 32 by 36 inches, one-fourth inch thick. This board contains 8 square feet and weighs 12 pounds. A special board three-eights inch thick is also made. The board made by the American Cement Plaster Company is three-eighths inch thick, is reinforced by wood fibre, and has only a surface layer of felt. This board is made in sizes of 32 by 24 inches, 32 by 18 inches, and 24 by 18 inches. The plaster board is nailed directly to the studding, thus taking the place of lath. The horizontal joints are broken on each side of the partition and the vertical joints on opposite sides. Several advantages are claimed for the wall board over wood lath, among them being the greater strength given to the walls, the fire proof and insulating qualities of the board, the rapidity with which it can be plastered, as it does not require wetting before the plaster is applied. It can also be sawed, or penetrated by an ordinary auger.

The fireproof studding "gypsinite" is made by the United States Gypsum Company. It consists of two selected nailing strips imbedded in "gypsinite concrete," a plaster preparation. It can be nailed into and can be sawed as easily as wooden studding. Connections with plates, sills, and bridging are made with galvanized iron clips. Partitions of this studding with plaster board and plaster or with metal lath and plaster are entirely fireproof. The method of applying the plaster board to the studding is shown in figure 26.

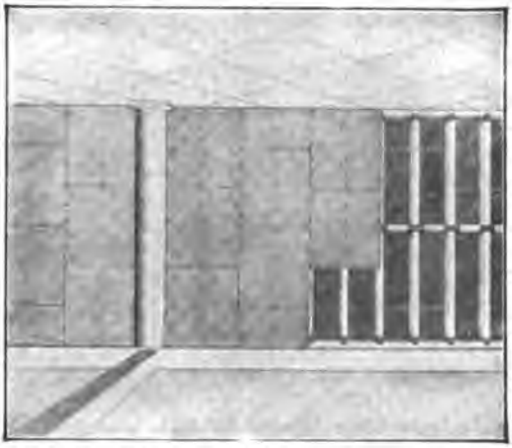


Fig. 26.—Plaster board and "gypsinite" studding.

Cement tile or partition block are made by pouring wo...-fibre plaster into moulds of suitable size and shape. A con-tinuous process of manufacture used by the Roman No-- Plaster Company at Bickford is described in the previous cha--

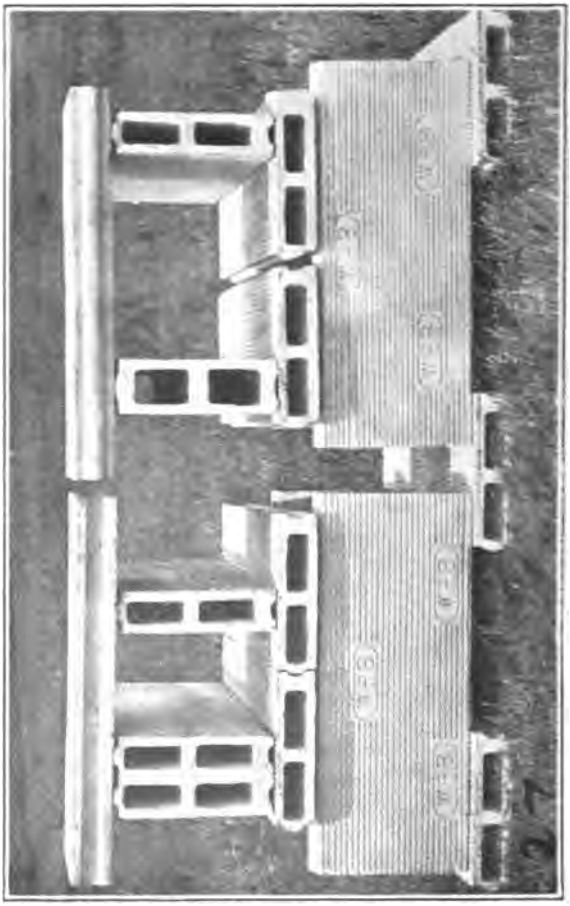


Fig. 27.—Gypsum tile made by Roman Nose Gypsum Company.

ter. The shape of this tile is shown in figure 27. The other companies manufacturing the tile in Oklahoma are the United States Gypsum Company, making the "Pyrobar" tile (fig. 28). and the American Cement Plaster Company, making the

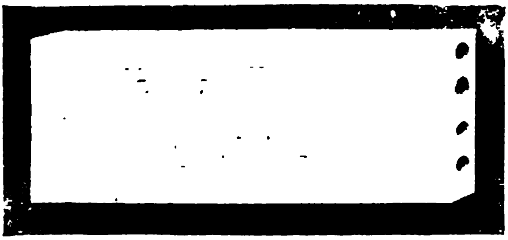


Fig. 28.—Pyrobar gypsum tile.

"American" tile. The advantageous points of the gypsum tile are given by the manufacturers in their literature as follows:

1. Fireproof qualities: practically unaffected by fire; zero co-efficient of expansion; resists action of water under average actual fire conditions, remaining plumb and true and requiring replastering on fire side only for complete restoration; transmits to the opposite side less than 5 per cent of temperature of fire side.

2. Forty per cent lighter than hollow clay tile and affords a corresponding saving of dead weight in building.

3. Is an efficient non-conductor of sound.

4. When laid in gypsum mortar the tile form an essentially monolithic partition of great stiffness.

5. The tile are straight and true and can be sawed into any desired size or shape, thus permitting neater workmanship than clay tile.

6. Give a stain-proof wall .

7. Economical on account of the light weight and large size of individual blocks. Can be laid more rapidly than clay tile.

8. Plastering grounds and trim can be nailed directly to the tile.

9. Electric installation and any alterations to buildings can be made easily and neatly since the tile can be sawed.

10. The tile make excellent column protection and wall furring because of its heat insulating properties.

The size and widths of gypsum tile for various ceiling heights made by one company are as follows:

Sizes and weights of gypsum tile.

Size	Weight per sq. ft., pounds.	For ceiling heights, feet
2 by 12 by 30 inches, hollow	6	Furring
2 by 12 by 30 inches, solid	8.8	10
3 by 12 by 30 inches, hollow	9	13
3 by 12 by 24 inches, solid	12.4	Book tile
4 by 12 by 30 inches, hollow	11	17
5 by 12 by 30 inches, hollow	13.6	25
6 by 12 by 30 inches, hollow	15.6	28
8 by 12 by 15 inches, hollow	21.6	40

Gypsum plaster as a building material for outside work.—Gypsum plasters are cheap and easily applied so that if the material were resistant to the weather it would be an excellent exterior plaster. However, no process has yet been devised which will render the gypsum plaster weather proof. Some schemes have been devised which are tolerably successful, but the product is too expensive to be used in a large way. Except in arid climates gypsum cannot be considered as a material suited to outside work.

Temporary buildings are often finished with gypsum plaster know as staff. The great expositions have used immense quantities of such plaster and since the buildings are in service only a few months the material is entirely satisfactory. The only case, to the writer's knowledge, in which an attempt has been made to use any of these buildings for a number of years is the building of the Field Columbian Museum at Chicago. This building was used as the Fine Arts building of the Columbian Exposition in 1893 and has been occupied by the Museum ever since. For several years, the exterior walls have been in a half-ruinous condition and constant repairing has been necessary to keep the building habitable.

The Germans use plaster coated with water-proofing substances for relief work and exterior ornaments of buildings.

Wilder[52] describes the methods of making these ornaments as follows :

"Figures and reliefs are characteristic of German architecture. When not made out of stone these ornaments consist of cement and gypsum. Gypsum ornaments are hardened, colored and made so weather proof that only close examination reveals the fact that they are not made out of solid material. The gypsum figures and reliefs cost but a small fraction of the sum which would be required to produce the same ornaments in the stone which they so skillfully simulate. The ornaments are cast in moulds of wood, metal, clay, gypsum or lime. If the ornament is simple, the mould may be in a single piece, but if complicated the mould is made of a number of easily detachable pieces. The fact that gypsum expands on hardening, filling all of the interstices of the mould, renders it a most valuable material for making casts.

"Extremely hard figures capable of taking a polish may be made by subjecting the gypsum to steam, then filling the form with the steamed plaster (stuck gypsum) and submitting the form to hydrostatic pressure. * * *

"As protection against the weather the following processes are recommended: warm the gypsum object and rub the surface with a mixture of three parts linseed oil varnish and one part white wax; or, impregnate the surface with sulphur balsam, consisting of fat oil in which sulphur has been dissolved (for instance, linseed oil at 160°C. and 10 per cent of sulphur). Another mixture highly recommended for protecting the surface of gypsum building ornaments is three parts of linseed oil, lead oxide equal to one-sixth the weight of the linseed oil and one part wax. Or the surface may be bronzed and otherwise protected with metal coatings.

"Mixtures containing gypsum which are recommended for ornamental purposes are: One part gypsum plaster and one part lime; four parts gypsum, three parts white chalk or lime, and one part fine sand. For white ornaments, one part fine gypsum plaster, two parts white chalk, with a limited amount of lime water; for gray figures, a mixture of gypsum plaster

[52] Wilder, Frank A., Gypsum industry of Germany: Iowa. Geol. Survey, vol. 12, 1902, pp. 203-204.

with fine coal dust. The latter mixture gives a considerable degree of hardness, but when objects made from it are exposed to moisture and frost they fall to pieces."

Artificial stones from gypsum.—Various plans for treating gypsum to imitate marble and other materials have been tried and have proven successful in a small way. The German method of making imitation ivory and marble is described by Wilder[3] as follows:

"*Stuck gypsum (calcined plaster) used to produce effect of ivory.*—The fine white gypsum powder is heated and mixed with paraffin which has also been heated to 65° to 70°C. The mass is taken out and any extra paraffin drained off. If the gypsum contains colored impurities they are made all the more conspicuous by the oil. A more vivid color may be given the mass by adding coloring matter to the paraffin.

"*Stuck gypsum (calcined plaster) used in making artificial marble.*—The ingredients are gypsum, finely sieved and burned limestone, and coloring matter. Lime is used in only limited quantities and its function is simply that of a retarder so that the mass may not set within thirty minutes. The mass is worked up in a ball, the coloring matter being worked through in streaks, like the veins in marble. The ball is cut with wire into slabs, which are placed at once upon the wall or over the surface to be covered. When the surface has hardened it is smoothed with pumice and rubbed with a thin solution of gypsum, which closes any pores. It is then rubbed with tripoli and olive oil and finally polished with a woolen cloth. Earth colors are suitable for this purpose, and also any used by the frescoers which are not destroyed by lime. A great many processes for producing marble-like effects with gypsum plaster have been patented in Europe. One of the most recent was issued to Pietro Viotti. In this process 1,500 grams of borax and 150 grams of magnesia are fused together and when cooled mixed with seventy-five kilograms of gypsum."

Gypsum blocks may be hardened by calcining them, allowing them to cool, (usually with the outer air excluded to prevent cracking) and immersing them for a few minutes in a solution of aluminum sulphate and drying them.

[3]loc. cit.

Flooring plaster or estrick gypsum.—This material is extensively used in Germany, but so far has not been manufactured in the United States. It is made by calcining lump gypsum at a temperature of 400°F. or higher. This plaster is completely dehydrated but still retains the crystalline form of the half-hydrate, $CaSO_4 \frac{1}{2} H_2O$, or plaster of Paris. The flooring plaster, although it is what is commonly known as "dead burned" plaster in the United States, takes up water very slowly and sets similarly to the plaster of Paris or stucco gypsum and forms a very hard plaster. If the burning is conducted at a temperature greatly in excess of 400° or 500°F., or if the material remains at this temperature for too long a time, the plaster is truly "dead burned" and will not set on the addition of water[54].

The method of burning the flooring gypsum and the kiln used for this purpose have been described in the previous chapter. As is indicated by its name, estrick or flooring gypsum is principally for floors. The method of using it is described by Wilder[55] as follows:

"The following methods of applying estrick gypsum to floors are recommended by German authors. A bedding of sand 5 centimeters thick is first laid down. If sand is expensive, this may be reduced to 3 centimeters. On this the estrick gypsum mortar is spread to a thickness of 3 centimeters. In preparing the gypsum mortar a box about 1.8 meters long, 1.2 wide and 0.4 high is used. In this box the gypsum is mixed with water till a thick mortar is formed. The water is placed in the box first and into it the gypsum is poured. The gypsum mortar so made is laid on the sand foundation in the following manner: At a distance of three feet from one of the walls a wooden strip in thickness equal to that of the desired estrick layer, is placed parallel to the wall. Between this and the wall the gypsum plaster is poured. After the water in the mortar has in part soaked into the sand and in part evaporated, the mortar is rubbed over with a steel bar and partially smoothed. Perhaps an hour later it is rubbed over again and made still

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[54]For complete discussion on the effect of temperature and length of burning on estrick gypsum see translation in Eckel's cements, limes, and plasters, of paper by Van't Hoff and Just.

[55]Wilder, Frank A., Gypsum industry of Germany: Iowa Geol. Survey, vol. 12, 1902, pp. 207-208.

smoother. Then the wooden strip is removed to a distance of three feet and the process repeated. The edge of the part previously prepared is beveled or hollowed so that the new strip may lap over it and become definitely a part of the one already made. At the end of twenty-four hours the floor will be so hard that the foot of an adult makes no dent in it. It is then vigorously tamped till water again appears on the surface. Finally it is smoothed with a steel bar.

"For floors of dwellings a thickness of 3 centimeters for the gypsum covering is regarded as sufficient. For granaries 5 centimeters is recommended. For one square meter of estrick floor, 3 centimeters thick, 100 pounds of gypsum are sufficient. In Germany the cost of a square meter of sand 5 centimeters thick is estimated at three cents, the gypsum for three centimeters coating at twelve cents, and labor at eight cents, making a total cost per square meter of twenty-five cents, or about twenty-two cents per square yard."

Care must be taken to protect the foundation from moisture and to prevent too rapid drying of the mortar. The floors when estrick gypsum has set and dried are hard and durable and are much used in Germany for indoor work and for covered walks in the place of Portland cement.

Hard-finish plasters.—The following description of the various hard-finish plasters is taken entirely from Wilder's work previously quoted (page 205). A fuller discussion of the composition and properties of Keene's cement is given by Eckel, in Limes, cements and plasters, pages 76 to 78.

"*Other imitation marbles and hard cements in which stuck gypsum (calcined plaster) is used.*—The following cements, in which gypsum is the chief ingredient, are alike in their essential properties. They are usually hard, durable, uniform in strucure, set slowly and take a high polish. They may be fastened in thin slabs to nearly any kind of background, do not crack in drying and admit of an admixture of coloring matter without loss of strength. They stand in hardness about one-half way between Portland cement and ordinary stucco.

"1. Keene's cement or English white cement is a slow setting alum gypsum. Gypsum, preferably a white variety, unground, is burned at a red heat, then soaked in an alum

solution, burned a second time at a red heat, and then finely ground, when used it is mixed with an alum solution. If it is used with 20 per cent water, it has a tensile strength of seventy pounds and a crushing strength of 800 pounds per square centimeter.

"2. Parian cement consists of 44 parts stuck gypsum (calcined plaster) and one part calcined borax. The gypsum is saturated with water having the borax in solution and burned at a red heat. It sets slowly and dries in five or six hours. It is used as a covering for both inner and outer walls and may be painted or covered with paper. It should be mixed with as little water as possible, and must not come in contact with fresh lime.

"3. Scagliola is a mixture of finely burned gypsum, ground selenite and lime-water, often made into slabs and used for wall decoration.

"4. German marble cement is like Keene's cement, but possesses greater hardness, having after four weeks a tensile strength of ninety-six pounds and a crushing strength of 850 pounds per square centimeter, when made up with 20 per cent of water. It is used for the most part for outside facades, and must be protected on the weather side against rain by a coating of varnish. It is made by the Walkenruder Gyps Fabrik at Walkenried in the Hartz."

TESTING OF GYPSUM PLASTERS.

No tests on the manufactured products were made in the preparation of this report. The tensile and crushing strength of these plasters has already been shown by tests and by actual experience to be ample for any purpose to which the material is likely to be put. The time of setting is controlled by the amount of retarder added so that test of the setting time of one carload or of one day's output would give no information as to the next carload or next day's output. The time of setting for each carload is usually determined at the mill. In many cases the gypsum used is so uniform that a given amount of a standard retarder will always give the same retardation or so nearly the same as to be depended on for working purposes. The effect of retarder on crushing and tensile strength has been

much discussed. Tests seem to show that even small amounts of retarder weaken the strength of the plaster to some degree, but not sufficiently to have any serious effect.

The following notes are compiled from the reports of Grimsley on the gypsum of Michigan and of Wilder on the gypsum of Iowa and from Eckel's Limes, cements and plasters. They serve only to show the general properties of the plasters. There is considerable variation in the results of the tests on different plasters, but none of the plasters tested fall low enough to cause them to be rejected.

The tensile strength of the plasters tested has varied from 107 to 336 pounds per square inch for neat plaster at 1 day; from 128 to 638 pounds per square inch at 1 week; from 168 to 595 pounds per square inch at 1 month, and from 308 to 593 pounds per square inch at 6 months. The addition of sand to plaster in the ratio of 2 parts of sand to 1 part of plaster reduces the tensile strength to approximately one-half to two-thirds the tensile strength of the neat plaster. The difference between the tensile strength of the neat plaster and the plaster mixed with sand is greatest when the plaster is one day old and decreases up to 3 or 6 months. Old plaster if kept dry attains almost the same tensile strength as new plaster in a few weeks. The compressive or crushing strength of neat plaster varies from about 1,300 to 2,000 pounds per square inch. The addition of two parts of sand causes a decrease in the crushing strength. In the Wyoming cement plaster the addition of 2 pounds of retarder, made from dried cactus, per ton of plaster caused a decrease of 20 to 25 per cent in the crushing strength. The addition of 4 pounds per ton decreased the crushing strength about 27 per cent. Some of the manufacturers of Oklahoma conduct tensile strength tests continually and claim that they can determine no appreciable difference between the tensile strength of the neat plasters and that of plasters with 4 to 6 pounds of retarder per ton. The adhesive strength has been made the subject of a few tests but the tests have not been standardized and have given little information of value.

STATISTICS OF PRODUCTION.

In order to give an idea of the importance of the gypsum industry the following statistics are taken from the Mineral

sources of the United States, for 1911, compiled by the U. S. ological Survey:

Crude gypsum production in the United States in short tons.

0	90,000	1906	1,540,585
5	90,405	1907	1,751,748
0	182,995	1908	1,721,829
5	265,503	1909	2,252,785
0	594,462	1910	2,375,394
5	1,043,202	1911	2,323,970

Production of gypsum in other countries, 1906-1910, in short tons.

Year	France.		United States		Canada	
	Quantity.	Value.	Quantity	Value	Quantity[1]	Value
6	1,517,603	$2,423,615	1,540,585	$3,837,975	417,755	$591,828
7	1,559,685	2,598,828	1,751,748	4,942,264	485,921	646,914
8	1,553,173	2,559,521	1,721,829	4,075,824	340,964	575,701
9	1,460,271	2,426,110	2,252,785	5,906,738	473,129	809,632
0	(2)	(2)	2,379,057	6,523,029	525,246	934,446

Year	United Kingdom		German Empire (Bavaria)		Algeria		Cyprus	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity[3]	Value
06	252,030	$362,761	55,956	$22,011	30,809	$85,446	23,069	$55,658
07	263,779	431,313	53,085	17,456	29,101	75,907	27,114	68,146
08	255,714	431,551	56,563	18,953	28,109	66,537	23,511	57,561
09	267,676	418,242	56,911	19,254	31,967	75,656	12,230	29,754
10	286,226	478,095	59,962	22,658	(2)	(2)	(2)	(2)

[1]Quantity sold. [2]Figures not yet available. [3]Exports.

Production of gypsum in the United States in 1910 and 1911, by States and uses, in short tons.

1910.

State	Number of mills reporting	Total mined	Sold without calcining: Ground for land plaster, Quantity.	Sold without calcining: Ground for land plaster, Value	Sold without calcining: For Portland cement, paint, bedding plate glass and other purposes, Quantity.	Sold without calcining: For Portland cement, paint, bedding plate glass and other purposes, Value	Sold as calcined plaster: Quantity.	Sold as calcined plaster: Value.	Total value
Alaska, Arizona, Montana, New Mexico, South Dakota, and Wyoming	11	211,080	280	$1,009	17,053	$38,476	121,898	$614,507	[illegible]
California	7	45,901	4,960	14,185	17,318	46,090	31,824	181,928	[illegible]
Colorado	4	45,820	......	......	(1)	(1)	37,062	118,809	[illegible]
Iowa	6	322,713	6,159	8,312	30,532	38,683	230,932	896,854	[illegible]
Kansas	7	135,088	[2]3,751	7,223	41,859	49,971	75,445	320,028	[illegible]
Michigan	8	357,174	7,097	9,900	57,469	78,478	240,905	579,823	[illegible]
Nevada and Oregon...	5	103,329	4,410	9,322	(1)	(1)	86,123	443,596	[illegible]
New York	13	467,339	12,494	25,462	160,666	240,148	248,862	888,367	[illegible]
Ohio and Virginia.....	4	292,987	10,479	24,071	19,292	37,767	226,516	759,375	[illegible]
Oklahoma	10	162,788	(3)	(3)	10,924	13,896	116,968	442,191	[illegible]
Texas	3	188,559	(3)	(3)			135,801	485,169	
Utah	4	46,279	4,185	10,841	[4]12,301	15,663	31,333	122,585	[illegible]
Total	82	2,379,057	53,815	110,325	368,014	559,172	1,583,669	5,853,532	[illegible]

1911.

State	Number of mills reporting	Total mined	Sold without calcining: Ground for land plaster, Quantity.	Sold without calcining: Ground for land plaster, Value	Sold without calcining: For Portland cement, paint, bedding plate glass and other purposes, Quantity.	Sold without calcining: For Portland cement, paint, bedding plate glass and other purposes, Value	Sold as calcined plaster: Quantity.	Sold as calcined plaster: Value.	Total value
Alaska, Arizona, Georgia,[5] Illinois,[5] Minnesota,[5] Missouri,[5] Montana, New Mexico, South Dakota, Washington,[5] and Wisconsin[5] ...	8	129,193	382	$1,374	13,537	$43,672	151,376	$784,164	[illegible]
California	6	43,855	7,399	18,280	15,726	42,193	25,144	143,791	[illegible]
Colorado	4	26,226	......	......	(6)	(6)	19,194	59,936	[illegible]
Iowa	6	354,204	(7)	(7)	(7)	(7)	229,890	857,287	[illegible]
Kansas	6	122,579	[10]4,736	8,702	[8]47,197	47,765	70,795	288,736	[illegible]
Michigan	8	347,296	15,548	15,706	63,502	69,549	206,299	488,671	[illegible]
Nevada and Utah.....	6	133,960	4,893	9,253	[9]15,562	23,339	98,419	413,463	[illegible]
New York	12	472,834	7,960	17,426	149,722	213,903	268,785	968,267	[illegible]
Ohio and Virginia.....	5	360,858	11,962	26,832	21,166	41,880	283,672	987,856	[illegible]
Oklahoma	10	108,653	(7)	(7)	8,194	9,605	75,081	277,986	[illegible]
Texas	4	179,625	(7)	(7)	(7)	(7)	139,023	486,162	[illegible]
Wyoming	3	44,687	......	......	......	......	30,740	116,237	[illegible]
Total	78	2,323,970	52,880	97,573	334,600	491,906	1,598,418	5,872,556	[illegible]

[1]Included in Utah.
[2]Includes Oklahoma and Texas.
[3]Included in Kansas.
[4]Includes Colorado, Nevada, and Oregon.
[5]Produces no crude gypsum.
[6]Included in Nevada and Utah.
[7]Included in Kansas.
[8]Includes Iowa, Texas, and Oklahoma.
[9]Includes Iowa and Texas.
[10]Includes Colorado.

CHAPTER IV.

THE GEOLOGY OF THE GYPSUM BEARING AREA OF OKLAHOMA.

INTRODUCTION.

The gypsum deposits of Oklahoma are a part of the Redbeds which form the surface rocks of the greater part of the western half of the State. In order to give the geologic relations of the gypsum members, the geology of the Redbeds as a whole is considered rather briefly in this chapter. The detailed stratigraphy of the gypsum-bearing formations is given as completely as possible in the succeeding chapter.

GEOLOGY OF THE REDBEDS.

DISTRIBUTION.

The Redbeds area of Oklahoma forms a part of the larger area which extends from southwestern Kansas almost to the Pecos River in southwest Texas. The outcrop at the north end is narrow, but widens rapidly to the south and includes most of the western half of Oklahoma. From Red River south the belt narrows until on Colorado River it is about one-half as wide as it is in Oklahoma. The narrowing of the outcrops in both directions from Oklahoma is accounted for in large measure by the covering of the Redbeds by younger formations, and in part by the thinning of the beds. To the west, south, and north the beds disappear under younger formations, —Lower or Upper Cretaceous or Tertiary. They are continuous beneath these younger formations to the west and reappear in a belt along the base of the Rocky Mountains in New Mexico. A narrow strip along Canadian River connects the New Mexico and Oklahoma areas across the Panhandle of Texas. Areas

of red rocks in the eastern part of Colorado and Wyoming probably belong to the same great body of Redbeds.

PHYSIOGRAPHY.

Topography.

The western portion of Oklahoma is a plain which slopes southeastward. In the region underlain by the gypsum the streams have cut many canyons, so that while in general the region is a plain, the gypsum area is hilly and is usually considered as a physiographic unit, the "Gypsum Hills Region," which separates the Low Plains to the east from the High Plains which lie to the west of the gypsum area.

Drainage.

Across the gypsum hills, seven rivers run in a general southeast direction. These are from north to south, Salt Fork of Arkansas River, Cimarron, North Canadian, South Canadian, Washita, North Fork of Red River, and Salt Fork of Red River.

Salt Fork of Arkansas River emerges from the gypsum hills just at the Oklahoma-Kansas state line in northern Woods County. Two of its tributaries, Yellowstone and Greenleaf Creeks, have canyons reaching back a few miles into the gypsum hills.

Cimarron River enters the State from Kansas at the northeast corner of Harper County and forms the boundary between Harper, Woodward, and Major Counties on the southwest and Woods County on the northeast. For 8 or 10 miles it flows through a rather narrow valley between the gypsum hills, which form steep bluffs 200 to 300 feet high on either side, and then the valley widens gradually to about 15 miles farther down where the hills on the north side drop back from the Cimarron and swing to the west on the south side of Salt Fork of Arkansas River. On the south side of the Cimarron the hills continue, gradually getting farther from the river, at Fairview the hills are about 8 miles from the Cimarron and from this point southeastward the hills are nearer to the North Canadian than to the Cimarron. On the north side of the

Cimarron is a belt of sand hills varying from 1 to 2 miles to 20 miles in width. A large number of tributaries rise on the divide to the southwest of the gypsum hills and flow north and northeast through the canyons in the gypsums into the Cimarron. About 18 miles below the Kansas line, Buffalo Creek joins the Cimarron from the west. It is a long creek which drains a large portion of Harper County. Between Buffalo Creek and the vicinity of Fairview are several creeks flowing north which are not over 10 to 15 miles long and which are spaced 5 or 6 miles apart. From Fairview southeast the tributaries are longer and flow due east to the river.

North Canadian River has an exceptionally narrow valley for so long a stream. It is formed by the confluence of Beaver Creek and Wolf Creek, near Fort Supply, and flows to the southeast very nearly parallel to the Cimarron and from 20 to 25 miles distant from it. The gypsum escarpment discussed in connection with the Cimarron River lies within 5 to 10 miles of the North Canadian from Watonga to El Reno, but faces the Cimarron so that the North Canadian receives very little drainage from the north. A few fairly large tributaries join it from the south from southern Woodward and northern Dewey Counties, but from the southeast corner of Woodward County to the center of Canadian County, where it leaves the gypsum hills, the North Canadian is usually less than 15 miles distant from the South Canadian, so the tributaries are few and short.

Like the Cimarron the North Canadian has a belt of sand hills along its north bank which locally reaches a width of 10 to 12 miles. The gypsum hills along the North Canadian are rounded and there are no steep gypsum capped bluffs as there are on the Cimarron.

South Canadian River enters Oklahoma from Texas a little north of the middle of the north-south line between the two States, and flows in a winding course with a general easterly direction. It forms the boundary between Ellis and Roger Mills Counties and enters the gypsum hills where it bends to the north about 12 miles west of the Roger Mills-Dewey County line and continues through them with a great bend to the north, another to the south and back to the north to Taloga in north-central Dewey County. Here it leaves the gypsum hills and

turns abruptly southeast. Through the gypsum hills the sand hills are not so conspicuous along the north side of the river, although they make a broad belt both above and below the gypsum area. The gypsums along the South Canadian do not belong to the same formation as those along the Cimarron and are not so thick nor so regularly stratified. They do not make a continuous escarpment, but cap rather steep sided hills. The tributaries from the north and the south are about equal in number and are all short, the longest being about 15 miles long, and the most of them less than 10 miles.

Washita River differs from the other streams of this region in having steep mud banks. There are no sand hills along its course. It enters the State from Texas only 8 or 10 miles south of the South Canadian, and flows south and east across Roger Mills County, southeast across the southwestern part of Custer County, east and south across the eastern part of Washita County, at the south line of which it turns east and flows in that direction across Caddo County and out of the area under consideration. The Washita enters the gypsum hills near the Roger Mills-Custer County line and continues in them with the exception of a few miles in southeastern Washita and northeastern Kiowa Counties, to Anadarko in southeastern Caddo County. The gypsums are those of the Greer formation and do not form a continuous escarpment as do the gypsums along the Cimarron, but some of the thickest ledges in the entire area are exposed along the Washita in eastern Washita County.

North Fork of Red River enters Oklahoma from Texas about the middle of the west line of Beckham County and flows east and southeast to the corner of that county, then in a meandering course to the south between Greer and Jackson Counties on the west and Kiowa and Tillman Counties on the east. The only exposures of gypsum along this river are in the extreme southeastern portion of Beckham County, where the Wichita Falls & Northwestern Railway crosses the river south of the town of Carter. Here heavy ledges of gypsum extend for several miles along the northeast bank of the river. Along the upper course of Elm Fork, the principal tributary of North Fork, in northern Harmon and western Greer Counties, are four or five ledges of gypsum which form an escarpment resembling the one along Cimarron River.

Salt Fork of Red River parallels Elm Fork about 10 to 12 es south of the latter through Harmon and western Greer inties, turns south at Mangum and flows south approxitely parallel to North Fork and from 10 to 12 miles west it. The hills along the Salt Fork in Harmon and Greer inties are much more rounded than those along Elm Fork few miles north, and, except at Mangum and for a short tance above, good exposures are not common. After it turns ith the course of the river lies outside the gypsum hills.

CHARACTER OF THE ROCKS.

The Redbeds consist entirely of red shales and sandstones. ie red color varies greatly in shade in different horizons and om place to place in the same horizon. All graduations from rmillion to maroon or very deep red brown can be observed short distances where good exposures are common. In neral, however, the vermillion and brick reds seem to be ore common in the lower formation in which shales predomiite and the deeper reds in the upper formations in which indstones are more abundant. The sandstones are usually mposed of very fine, rounded grains, and are cross-bedded and nticular to a pronounced degree. They often grade into shales very short distances, but probably more often they pinch it very quickly and are replaced abruptly by shales which ntain very little sand. Locally the sandstones are quite arse and in a few instances are conglomeratic.

The shales are usually very fine-grained, slightly consoliated, and very plastic, with high shrinkage in drying. They sually contain considerable quantities of soluble salts. The olor of the clay shales is usually a brighter brick red or verillion than that of the sandy shales or the sandstones.

The gypsums, although they occur in ledges of up to 60 r more feet in thickness and cover considerable areas, are elatively unimportant when considered as a part of the Rededs as a whole. Closely associated with the gypsums are white o greenish sandstones and shales, which, on account of their olor, are often very striking in fresh exposures. The stratifiation of these whitish or greenish rocks is very irregular. A reenish band may appear, thicken to 5 or 6 feet, and pinch

out in a few rods. The stratification of these light colored bands is probably no more irregular than that of the minor variations in the red rocks, but is much more noticeable on account of the contrast in colors. Two or three ledges of dolomite, usually less than 5 feet in thickness, are the only carbonate rocks.

THICKNESS.

The character of the Redbeds as noted in the preceding paragraphs renders it impossible to make an accurate determination of their thickness by measuring across the outcrop. The stratification is so irregular that a section taken at one place cannot be duplicated even in its larger features at a distance of a mile. In detailed sections great variation is found in the distance of a few rods. The lenticular nature of the sandstones and shales and the crossbedding of the sandstones make it almost impossible to determine the dip of the rocks from observation of short exposures. In the upper portion of the beds some general horizons can be followed and the thickness between them can be rather closely approximated. The only way of obtaining the thickness of the lower portion of the beds is from the logs of the few deep wells which have been drilled in this region.

Williston and Case[51] estimate the Redbeds in Kansas, Oklahoma, Texas, and eastern New Mexico, as "thicker than those of northern New Mexico [1,600 feet], probably reaching 2,000 feet in their totality." This estimate, however, is manifestly too small for the thickness of these beds in central Oklahoma. At Alva, near the Kansas line, a well passed through 1,100 feet of Redbeds. The well started some distance below the lowest gypsum and the mouth was consequently at least 750 feet below the top of the Redbeds as exposed in Oklahoma. To the south of the latitude of Alva the Redbeds thicken downwards rapidly to the middle of the State. At Shawnee a well which was started near the Pennsylvanian-Permian contact shows over 1,000 feet of red rocks. When it is remembered that much of the Permian and all of the Pennsylvanian in the latitude of Alva is non-red and that in the latitude of Shawnee these lower Permina rocks are red and that in addition 1,000

[51]Williston, S. W., and Case, E. C., The Permo-Carboniferous of New Mexico: Jour. Geol. vol. 9, 1911, p. 4.

feet or more of the uppermost Pennsylvanian rocks are red, we obtain a total thickness of over 3,000 feet. (750 feet above the mouth of well + 1,100 feet in well at Alva + 500 feet Permian rocks non-red at Alva but red at Shawnee, + 1,000 feet red Pennsylvanian in well at Shawnee = 3,350 feet.) The estimate of 500 feet for the Permian rocks which are non-red at Alva but red at Shawnee is from the thicknesses near the Kansas line. The thickness at Shawnee is probably greater.

In the deep well recently completed at El Reno the rocks were red and reddish brown to a depth of 2,050 feet. The thickness of the Redbeds formations occurring to the west and lying at a level above the mouth of this well is certainly not less than 900 feet and is probably greater. This well indicates a thickness of 3,000 feet or more for the Redbeds. Gould[55] gives the thickness of each formation of the Permian and the sum of these thicknesses gives a minimum of 2,250 feet for the Permian Redbeds. The maximum is probably 500 feet more. This with 1,000 feet or more of red Pennsylvanian gives between 3,000 and 4,000 feet of Redbeds in the central part of the State. The writer regards 3,000 to 3,500 feet as a very conservative estimate of the thickness of the Redbeds as exposed from the center or east of the center of the State to the west line.

AGE.

The Redbeds of the area under discussion were studied in Kansas and Texas several years before they were in what is now Oklahoma. Before 1893 the Kansas beds had been usually referred to the Jura-Trias or definitely to the Triassic[56], although some of the earliest observers had ascribed them to the Upper Carboniferous and some to the Lower Cretaceous. All these correlations were made on lithologic or stratigraphic grounds.

[55]Gould, Chas. N., Geology water resources of Oklahoma: Water-Supply Paper U. S. Geol. Survey No. 148, 1904.

[56]Hay, Robert, The Triassic rock of Kansas: Trans. Kans. Acad. Sci., vol. 6, 1889, p. 36; and Cragin, F. W., Geological notes on the region south of the great bend of the Arkansas: Bull. Washburn Col. Lab. of Nat. Hist., vol. 2, 1889; and A geological reconnoissance in southwestern Kansas: U. S. Geol. Survey, No. 57, 1890, pp. 20-21; Williston, S. W., Geol. Map of Kansas, 1892.

In 1891, White[57] described the invertebrate fossils from the Texas rocks supposed to be of the same age as the Kansas Redbeds, and Cope[58] had described the vertebrates from the Texas Redbeds some years previously. The age of the Texas beds was decided to be Permian, and although no fossils were found in the Kansas beds they were afterward classed as Permian by Hay[59] and Cragin[60] and by practically all subsequent writers. Recently the Permian age of the lower Redbeds in Texas has been more definitely established, especially on paleobotanic grounds. In the same paper[61] it is shown that the lower Redbeds in north Texas grade into non-red Permian rocks to the south.

In Oklahoma, as is shown later, the lowest part of the Redbeds is Pennsylvanian. The portion which is equivalent to the Permian of Texas has afforded a few fossils, vertebrate, invertebrate, and plant. The vertebrates were found at Nardin and Orlando, the former locality also furnishing invertebrates and plants. The vertebrate from Nardin was identified by S. W. Williston as a species of *Eryops*, a Permian amphibian; the invertebrate was provisionally identified by T. Rupert Jones as *Estheria minuta*, a crustacean usually regarded as Triassic; the leaves were too poorly preserved for identification, but according to Dr. Lester F. Ward appeared to represent Mesozoic forms. The fossils were found in the McCann sandstone quarry 5 miles southeast of Nardin and 12 miles southwest of Blackwell.

The Orlando locality is 2 miles northeast of the village of that name. The vertebrates collected there were identified and reported on by Case[62]. His list of species follows:

"*PISCES.*

"Elasmobranchii.

[57]White, C. A., The Texas Permian and its Mesozic types of fossils: Bull. U. S. Geol. Survey No. 77, 1891.

[58]Cope, E. D., Proc. Amer. Phil. Soc., vols. 17, 19, 20 and 21.

[59]Hay, Robert, Geology and mineral resources of Kansas: Eighth Bien. Rept. Kans. State Board Agri., pt. II, 1893, p. 101.

[60]Cragin, F. W., The Permian System in Kansas: Col. Col. Studies, vol. 6, 1896, pp. 2-3.

[61]Gordon, C. H., Girty, George H., and White, David: The Wichita formation of northern Texas: Jour. Geol., vol. 19, No. 2, 1911, pp. 120-134.

[62]Case, E. C., 2d. Bien. Rept. Okla. Dept. Geol. and Nat. Hist., 1902, pp. 62-68.

"Diacranodus (Pluerecanthus) *ampressus (?) Cope.

"Diacranodus is the name applied to this form by Garman ι 1885, Bul. Mus. Comp. Zool., vol. 12, and is the name used r Hay in his catalogue of the Extinct Vertebrata of N. A., ull. 179, of the U. S. G. S., it has been known variously as iplodus, Didymodus and Pleuracanthus; see the Catalogue by ay cited above.

"Dipnoi.

Sagenodus (?) sp.

BATRACHIA.

"Diplocaulus magnicornis (?) Cope.

"Diplocaulus limbatus (?) Cope.

"Diplocaulus salamandroides Cope.

"Trimerorhachis sp. Cope.

"Trimerorhachis leptorhynchus sp. nov.

"Cricotus sp. Cope.

"Cricotillus brachydens g. et. sp. nov.

"Eryops megacephalus Cope.

"Crossotelos annulatus g. et. sp. nov.

"REPTILIA.

"Pelycosauria.

"Naosaurus sp. Cope.

"Embolophorus (?) sp. Cope.

"Cotylosauria.

"Pariotichus ordinatus Cope.

"Pariotichus sp. Cope.

"Indet.

"Pleuristion brachycoelous g. et. sp. nov."

Fossil plants from a horizon near that of the vertebrates from Nardin and Orlando were collected near Perry and Red

Rock by David White and Charles N. Gould in the autumn of 1911. The material has not been fully worked up nor described, but the following preliminary statement concerning the plants was furnished the writer by Dr. White[63]: ". . . The flora is very distinctly and conclusively Permian. It contains an abundance of *Callipteris* with *Walchia* and *Gigantopteris*. *Callipteris conferta,* and species of *Walchia,* very likely identical with *Walchia gracilis,* and *Gigantopteris Americana* are among the most characteristic, the latter being nearly everywhere present in the Perry and Red Rock region. . . . There is no shadow of doubt as to the Permian age of the beds near Perry and Red Rock."

These fossils are from the lower part of the Redbeds in the latitude in which they are found. The only fossils found in the upper Redbeds in Oklahoma were found in the Whitehorse sandstone, a member of the Woodward formation, about 600 feet below the top of the Redbeds. The locality is at Whitehorse spring, two miles southeast of the Whitehorse Post Office, and 18 miles due west of Alva. The fossils are all invertebrates and were described and figured by Beede in an advance bulletin of the Second Annual Report of the Oklahoma Department of Geology and Natural History in 1902. Most of the type specimens of the collections were consumed by fire which later destroyed Science Hall at the University of Oklahoma. A new collection was made and the species redescribed and refigured[64] along with a collection from the Quartermaster formation (the topmost formation of the Redbeds) at Dozier, Texas.

Beede's conclusions are as follows:

"The fauna of the Quartermaster beds is different in some respects from that of the Whitehorse sandstone, several new elements having been introduced. * * *

"The faunas are somewhat heterogeneous as to origin. Some of the species seem to be directly derived from the Kansas Permian or Pennsylvanian, while others, as pointed out in the discussion of the species, are derived from the European Per-

[63]Person communication, dated Dec. 9 1912.

[64]Beede, J. A., Invertebrate Paleontology of the upper Permian red beds of Oklahoma and the Panhandle of Texas: Kans. Univ. Sci. Bull., vol . No. 3, 1907.

nian, especially that of Russia. There seems to be comparatively little resemblance to the Indian or Chinese forms. The fossils described as *Dielasma schucherti* Beede seem to have their closest allies in the Productus limestone of India, the only species, perhaps, with pronounced Indian affinities."

The types of the whole Quartermaster fauna were sent to T. W. Stanton, who pronounced them Paleozoic.

In addition to these fossils the dolomitic members immediately under the lower gypsum ledges in northwestern Oklahoma contain poorly preserved specimens of *Pleurophorus* and *Schizodus*. These occur also in a dolomite higher in the section near Eldorado in the extreme southwest part of the State.

Practically all the recent work then has tended to prove that all except the very lowest of the Redbeds are of Permian age. The only exception to this rule is the paper by Williston and Case[65] which has already been quoted. This paper is principally a description of the Redbeds of northern New Mexico, but some references are made to the Oklahoma deposits. In the northern New Mexico beds, as well as in the beds of Wyoming, upper Triassic vertebrates were found below the heavy gypsum ledges and the assumption is made that the gypsums of Oklahoma occupy the same horizon as the gypsums of northern New Mexico and Wyoming, and that therefore they and the sandstones above them are of upper Triassic age. A considerable thickness of the nonfossiliferous rocks below the gypsums is regarded as probably lower Triassic. The lower part of the northern New Mexico beds which contain vertebrates hitherto classed as Upper Pennsylvanian, apparently on the basis of a single cast of *Spirifer* as is indicated in the following quotation from the paper under discussion:

"It has been questioned by us elsewhere whether the vertebrate fossils found in Texas, Oklahoma, southern Kansas, Illinois, and Pennsylvania are really of Permian age. At the south side of the canon, the junior author found a perfect cast of a Spirifer, identified by Professor Schuchert as *S. rockymontanus* Marcou, a form occurring in Colorado in the Pennsylvanian. Though the specimen was found free, so that its exact

[65]Williston, S. W., and Case, E. C., The Phermo-Carboniferous of northern New Mexico: Jour. Geol., vol. 19, No. 1, 1912, pp. 1-12.

horizon could not be determined, its excellent preservation proves conclusively that it had not been carried far from its original bed, and inasmuch as vertebrate fossils are found in the deepest strata of the canon it seems quite certain that the specimen came from an intercalated bed among those yielding so-called Permian vertebrates. No other explanation seems possible. It is the conviction of both the present authors that the lowermost at least of the strata yielding vertebrate fossils are of Pennsylvania age. and this conviction is strengthened by the known position of the vertebrate horizons in Texas. Kansas, Illinois, and Pennsylvania, that of the last-named region definitely known to be Pennsylvanian."

The assumption is thus made that this horizon is the same as that carrying the vertebrates in Oklahoma, Kansas, Texas. Illinois, and Pennsylvania.

In view of the extreme irregularity of the stratification of the Redbeds and the distance which separates the Oklahoma deposits from those of northern New Mexico and Wyoming it seems to the writer that the correlations based on stratigraphy are decidedly open to question. Since there have been no Triassic vertebrates reported[66] from below the gypsums in Oklahoma and since the invertebrates from the Quartermaster considerably above the gypsums have been pronounced by different authorities to be Paleozoic, the age of the upper Redbeds of Oklahoma is regarded as Permian. The evidence of the plants and the invertebrates seems to show conclusively that the Enid formation is of Permian (including Permo-Carboniferous) age, even if it should be decided that the vertebrates should be placed in the Pennsylvanian instead of the Permian to which they have hitherto been ascribed by both the authors of the paper cited.

RELATIONS OF THE REDBEDS.

As has been shown in the preceding paragraphs the greater part of the Redbeds are generally regarded as of Permian age. In Kansas, only the upper portion of the Permian rocks are red, but near the Kansas-Oklahoma line the limestones and

[66]Up to Apr., 1913, Dr. E. C. Case spent a portion of the field season of 1912, studying the Oklahoma beds but results of his work have not been published.

non-red shales of the lower part of the system grade southward into red shales and sandstones so that the line between the red and non-red rocks descends lower in the system and the line between the outcrops swings to the east. As a result there is only a small area of non-red Permian rocks in Oklahoma, most of Kay county and portions of Osage, Noble, and Pawnee counties. The same change takes place in the rocks in the upper part of the Pennsylvanian system, *i. e.*, the limestones in Kansas give way to shales and sandstones in Oklahoma, with most of the sandstone dying out before they reach Arkansas River. To the south of the Arkansas the shales, and further south, the sandstones, take on the red color and become part of the Redbeds. The line between the red and non-red beds passes about midway between Pawnee and Stillwater and southeastward to Stroud, where it swings to the west of south and passes around the west end of the Arbuckle Mountains. The line between the Pennsylvanian and Permian enters the state a few miles east of the northeast corner of Osage County and bears a little to the west of south to the west side of the Arbuckle Mountains. The Pennsylvanian and Permian rock, then, occur in the following areas: (1) a large area of red Permian rocks, (2) a small triangular area of non-red Permian rock in Kay County and adjoining parts of Osage, Noble, and Pawnee Counties, (3) a small area of red Pennsylvanian rocks between the two lines mentioned above, and (4) the non-red Pennsylvanian rock covering most of the eastern half of the State.

The relations of the red and non-red rocks in Texas and in Kansas have been shown[67] to be similar. The Permian in central Texas is white (Albany), but becomes red to the north (Wichita), and limestones give way to sandstones and shales from south to north in the same way that the limestones of Kansas do from north to south.

The upper limit of the Redbeds in Oklahoma is irregular and is always one of unconformity. Limestone of lower Cretaceous (Comanchean) age occurs in small areas in Woods, Woodward, Dewey, Custer and Washita Counties. The patches

[67] Cummins, W. F., The Texas Permian: Tex. Acad. Sci., vol. 2, 1897, pp. 93-98; Adams, Geol. I., Stratigraphic relations of the Red Beds to Carboniferous and Permian in northern Texas: Bull. Geol. Soc. America, vol. 14, 1903, pp. 191-200; Gordon, C. H., Jour. Geol., vol. 19, 1911, pp. 110-125.

seldom exceed a few acres in extent and are on top of the hills or broad divides between the streams. The limestone is seldom over 3 or 4 feet thick and usually seems to have been let down from above as the shales and soft sandstones worked out from beneath it. In the rest of the area in Oklahoma the Redbeds pass under the Tertiary or Quaternary sands. In Texas the Dockum beds, Redbeds of Triassic age, occur unconformably above the Permian[68] Redbeds, but this formation is not present in Oklahoma.

CLASSIFICATION.

The classification of the Redbeds of Oklahoma has been discussed at some length by Gould in two papers, the Second Biennial Report of the Department of Geology and Natural History (Territorial) and Water-Supply Paper No. 148 of the United State Geologisal Survey. These reports are no longer easily obtained by the public, so in this report the classifications are briefly reviewed.

Cragin[69] published a classification of the Permian rocks in which he divided them into two series, the Big Blue or non-red series, and the Cimarron or Redbeds. He revised the classification of the Cimarron series in 1897.[70] Gould in the first of the papers cited above reviewed the previous work on the Redbeds and discussed the classification and stratigraphy of the Oklahoma deposits.

He used Cragin's classification as a basis, but owing to local differences in stratigraphy made important changes. The distinction between the Big Blue and the Cimarron series could not be kept in Oklahoma, since all the Permian rocks are red a short distance south of the Kansas line. The presence of two important gypsum bearing horizons gave a basis for classifying Redbeds into five divisions. These divisions and their subdivisions are as follows:

[68]Gould, C. N., Water-Supply Paper U. S. Geol. Survey No. 154, 1906, pp. 23-24.

[69]Cragin, F. W., The Permian system in Kansas: Colorado Col. Studies, vol. 6, 1896, p. 3.

[70]Observations on the Cimarron series: Am. Geologist, vol. 19, 1897, pp 351-363.

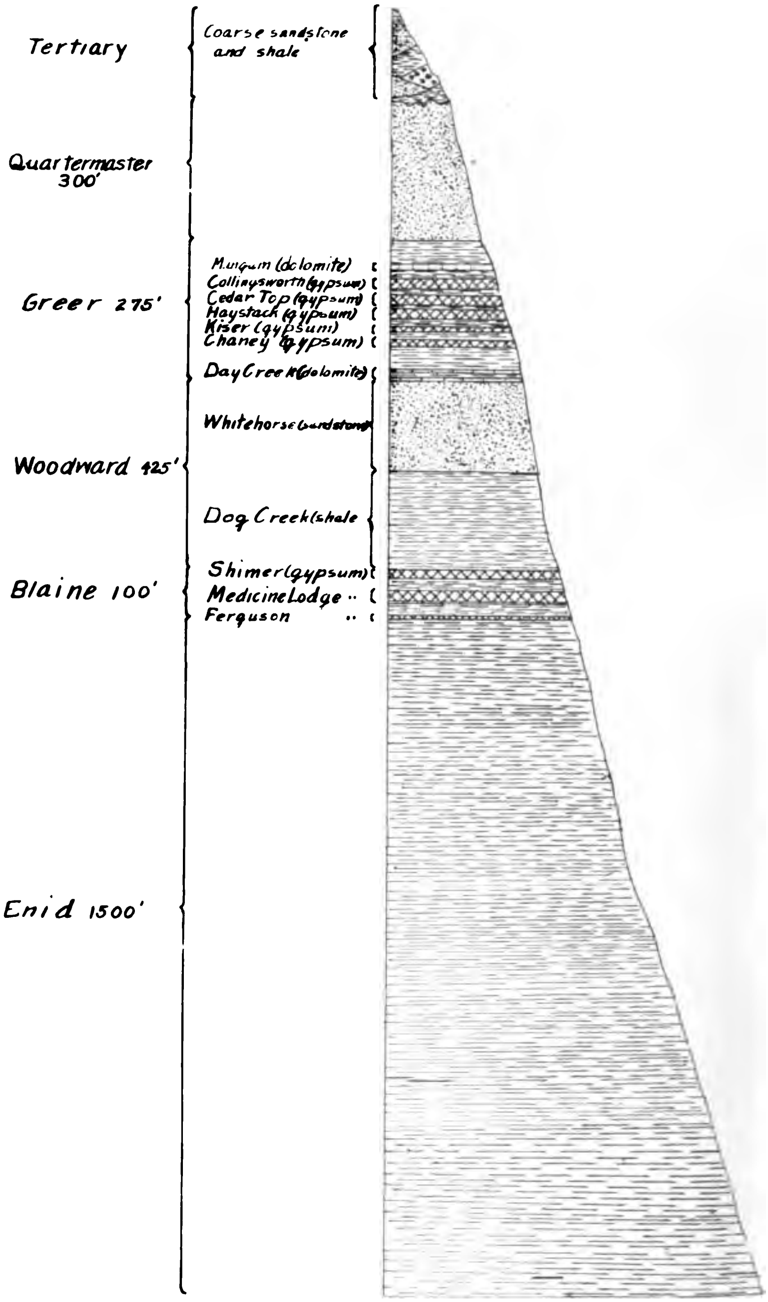
5. Quartermaster division.	
4. Greer division	Delphi dolomite. Collingsworth gypsum. Cedar-top gypsum. Haystack gypsum. Kiser gypsum. Chaney gypsum.
3. Woodward division	Day Creek dolomite. Red Bluff sandstones. Dog Creek shales.
2. Blaine division	Shimer gypsum. Altova dolomite. Medicine Lodge gypsum. Magpie dolomite. Ferguson gypsum
1. Norman division	

The term "division" was used "in a general sense, corresponding with its ordinary English meaning, to designate a larger or smaller sequence of strata which may in one instance correspond to a formation having a simple uniform lithologic character, or in another to a group of such formations."

In 1904 the second paper by Gould[71] appeared, which modified the 1902 classification in some particulars. The term "division" is superseded by the term "formation," which is used in the same sense. The term "Norman division," which included all the Redbeds below the lowest heavy gypsum, is abandoned, and the term "Enid formation" used for the Permian portion of these rocks, and the term "Chandler Beds" for the Pennsylvanian Redbeds. Of the minor divisions the terms Altova and Magpie dolomites are dropped, Mangum dolomite is substituted for Delphi dolomite and Whitehorse sandstone for Red Bluff sandstone. These changes leave the classification as follows:

Quartermaster formation.	
Greer formation	Mangum dolomite member. Collingsworth gypsum member. Cedartop gypsum member. Haystack gypsum member. Kiser gypsum member. Chaney gypsum member.
Woodward formation	Day Creek dolomite member. Whitehorse sandstone member. Dog Creek shales member.

[71]Gould, C. N., Geology and Water Resources of Oklahoma: Water Supply Paper U. S. Geol. Survey, No. 148, 1904


Tertiary
Coarse sandstone and shale
Quartermaster 300'
Mangum (dolomite)
Collingsworth (gypsum)
Cedar Top (gypsum)
Haystack (gypsum)
Kiser (gypsum)
Chaney (gypsum)
Greer 275'
Day Creek (dolomite)
Whitehorse (sandstone)
Woodward 425'
Dog Creek (shale
Shimer (gypsum)
Blaine 100'
Medicine Lodge ..
Ferguson ..
Enid 1500'

Blaine formation................	Shimer gypsum member. Medicine Lodge gypsum member Ferguson gypsum member.
Enid formation.	

STRATIGRAPHY.

Under this heading each of the formations is described in turn, commencing with the lowest. The Enid, Woodward, and Quartermaster, which contain no commercial gypsum, are dealt with rather fully and are not discussed elsewhere, and the Blaine and Greer are briefly discussed in order to give their general relationships and the detailed discussion of the stratigraphy and occurrence of the gypsum is taken up separately in the succeeding chapter. The areas of the outcrops of the different formations are shown on the map (fig. 29), and a generalized section is shown on the accompanying diagram (fig. 30).

Enid formation.

The Enid formation includes the rocks from the base of the Permian Redbeds to the lowest heavy gypsum ledge. The Pennsylvanian-Permian contact has been taken as a line crossing the Oklahoma-Kansas State line north of Pawnee, and extending south to that town, then west of south to Purcell, and south to the west end of the Arbuckles. The most recent work[72] has shown that the line should be drawn more nearly south from Pawnee. The upper limit of the formation is the base of the lowest gypsum of the Blaine formation. Owing to the lenticular nature of the gypsum this is not an exact limit, but is still a well defined horizon.

The line between the Enid and Woodward to the south or southeast of El Reno is very indefinite. The Enid formation occupies all or part of the following counties: Grant, Alfalfa, Woods, Major, Garfield, Noble, Payne, Lincoln, Logan, Kingfisher, Blaine, Canadian, Oklahoma, Cleveland, and McClain. The Redbeds in western Garvin and Carter Counties may belong in part to this formation.

The Enid consists almost entirely of red shales with soft, lenticular, red sandstones. The lower portion contains relatively

[72]Dr. J. W. Beede had a party in this region during the field season of 1911. The results of the work have not been published.

more sandstone than the upper, but the shales predomina throughout and comprise practically all of the upper par Throughout the Enid there are veins of white sandy materia These sometimes occur as lenses having considerable thickne at the center but pinching out rapidly. Lentils as much as feet thick in the center have been observed to pinch out in very few (10 or 12) rods. Some of the beds of white san are four feet, or even more, thick and cover areas of sever acres. In a few cases of exceptionally good exposures layer of this white sand less than an inch thick can be traced fo about one-fourth mile. The grains of the ordinary red sand stones, as well as those of the white layers, are very fine— large percentage passing a 200-mesh sieve. The shales grad from very sandy to clay shales. The latter are very fin grained, very plastic when wet, and have great drying shrinkage

The red color of both the sandstone and the shales is due to iron (ferric) oxide, which forms a thin coating over the grains of sand in the sandstones and presumably over the clay particles in the shales. In the uppermost 100 feet some of the shales have a green color. This color is probably due to some form of iron, but since these green shales are largely gypsiferous the color may be due to a compound of iron and calcium. The green color is often mistaken for copper stain.

At about 100 feet below the top of the formation the shales locally are very salty and give rise to salt springs at Ferguson in Blaine County, at the Big and Little Salt Plains on the Cimarron near the Kansas-Oklahoma State line, and at the Salt Plain near Cherokee. It is not to be understood that the salt occurs in these different localities at eactly the same horizon. The water carrying the salt at Cherokee is probably from a horizon considerably lower than that from which the salt water of the Springs at Ferguson come, while the salt horizon at the Salt Plains on the Cimarron is probably somewhat higher.

The shales for 25 to 30 feet below the gypsum ledge are very gypsiferous and the eposures show many veins of satin-spar and selenite. This vein material has almost certainly been derived from the solution of gypsum by water passing through the ledges above and has been deposited near the surface of the exposure by the evaporation of the water. Near the bottom of the strongly gypsiferous layer is a persistent layer 1 to 2

et thick of greenish selenite, the crystals of which are usually bout an inch long, and a single layer of concretions of pure hite, fine-grained gypsum. The concretions are in the shape f flattened ellipsoids and all lie with the long axis horizontal. 'he short or vertical diameter is usually about 2 inches and he long diameter 3 to 6 inches. These concretions lie almost r quite touching each other, forming a layer in the shale. On ccount of the persistence and unifoımity of this double layer t is believed that it is the result of original deposition.

The surface of the territory underlain by the Enid is in general a plain into which the streams have cut shallow valleys. The eastern portion of the outcrop is somewhat hilly on account of the sandstones in the lower part of the formation. This portion is covered by oak trees but the greater part of the area is prairie and only a few cottonwoods and elms occur along the streams. The thickness of the Enid was estimated by Gould[73] at 1,200 to 1,500 feet.

[73] Gould, C. N., Water-Suply Paper U. S. Geol. Survey, No. 148, 1904, p. 44.

Blaine formation.

The Blaine is the great gypsum-bearing formation of the northwestern part of the State and as such its stratigraphy will be discussed in detail in the next chapter. In this connection only a brief notice will be given to the character of the formation and its relations.

The Blaine formation consists typically of three gypsum members separated by shales. The formation always forms a pronounced escarpment, as the soft, easily eroded shales of the Enid are eroded much more rapidly than the gypsums. This escarpment and the outliers have been known since early times as the "Gyp Hills." The outcrop of the formation varies in width from about 1 to 6 or 8 miles. The hills enter the State from Kansas on the south side of the Salt Fork of Arkansas River, follow down that stream a few miles, swing back northwest up the Cimarron, cross the Cimarron just north of ehe Kansas-Oklahoma State line, and follow down the south bank of that river gradually getting farther from it. The formation is well developed as far southeast as Watonga, but from that point on the gypsums become lenticular and the formation plays out about 5 miles north of El Reno. The formation ranges from

75 to 100 feet thick. All discussion of the details of distribution and stratigraphy will be reserved for the succeeding chapter.

Woodward formation.

This formation is well described by Gould and since the field work for this report dealt very little with the formation and determined nothing new concerning it, his description is given in its entirety[74].

"*Dog Creek shales member.*—The Dog Creek member is composed mainly of clays, containing occasional thin ledges of magnesian limestone, which in places grade into a fair quality of dolomite.

"The ledges, however, are usually thin and rarely sufficiently conspicuous to be worthy of more than passing notice. Professor Cragin's original description of this member is as follows:*a*

" 'The Dog Creek * * * consists of some 30 feet, or locally of a less or greater thickness, of dull-red argillaceous shales, with laminae in the basal part and one or two ledges of unevenly lithified dolomite in the upper. The color of these shales resembles that which prevails in most of the divisions below rather than of the terranes above the Dog Creek.'

"In his second paper he modifies his description in this way:

" 'In central Oklahoma it is a great dolomite formation, laminated dolomite occupying a considerable part of the thickness' *b*

"In his second paper he suggests that the name Dog Creek be changed to Stony Hills. The writer agrees that the name Dog Creek is, perhaps, not the best that could be used. but in view of the fact that the dolomites which make up the Stony Hills in eastern Blaine County belong to the Blaine formation

[74]Gould, C. N., Water-Supply Paper, U. S. Geol. Survey No. 148, 1904, pp. 15-59.

*a*Cragin, F. W., the Permian system in Kansas: Colorado Col. Studies. vol. 6, 1896, p. 32.

*b*Cragin, F. W., Observations on the Cimarron series: Am. Geologist vol. 19, 1897, p. 358.

and do not belong to the Dog Creek, there seems to be no good reason for using the name Stony Hills to designate this member.

"Studies made during the last three years have demonstrated that in many parts of Oklahoma the thickness of the Dog Creek is much greater than that given by Professor Cragin. Near Quinlan, in eastern Woodward County, the aneroid readings indicate 225 feet as the thickness of these beds, measured from the top of the underlying gypsums of the Blaine formation to the sandstones of the next higher formation of this member, the Whitehorse, and in a number of localities 150 and 175 feet were recorded. Exposures are common along the top of the Gypsum Hills from Canadian County to the Kansas line and beyond.

"*Whitehorse sandstone member.*—The Whitehorse sandstone was also described (under the name Red Bluff sandstone) by Professor Cragin in his first paper, as follows:[a]

" 'This formation consists of some 175 or 200 feet of light-red sandstones and shales. * * * Viewed as a whole it is very irregularly stratified, being in some cases considerably inclined, in others curved, and this oblique and irregular bedding, being on a much larger scale than that of the ordinary cross beddings, at first glance gives the impression of dips, anticlines, synclines, etc., that have been produced by lateral pressure, the dips, however, being in various directions. * * * The Red Bluff beds exhibit the most intense coloration of any of the rocks of the series. When the outcrops are wet with recent rains their vividness of color is still greater, and the contrasts of their almost vermillion redness with other colors of the landscape is most striking. Spots and streaks of bluish or greenish gray sometimes occur in these rocks, but not to nearly so great an extent as in the lower beds. The sandstones of the Red Bluffs are generally too friable for building stone, but in some instances selected portions have proved hard enough for such use and are fairly durable.'

"In Oklahoma the Whitehorse member often weathers into conspicuous buttes and mesas. For instance, in eastern Woodward and western Woods Counties a row of these buttes, which

[a]Cragin, F. W., The Permian system in Kansas: Colorado Col. Studies, vol. 6. 1896. p. 40.

rise 100 to 200 feet above the surrounding country, extends from the vicinity of Whitehorse Springs, whence the name, southwest across the Cimarron, to the high divides beyond. To some of these buttes characteristic names have been given, as Lone Butte, Potato Hill, Watersign Hill, Wild Cat Butte, and the like. The noted Red Hill, between Watonga and Geary in southern Blaine County, is composed chiefly of the Whitehorse formation. South of Canadian River this sandstone thickens and on weathering often forms conspicuous bluffs, such as the famous Caddo County Buttes, southwest of Bridgeport. The Whitehorse sandstone is exposed along the Washita from near Chickasha, Ind. T. [Oklahoma], westward, and in the vicinity of Anadarko it forms bold bluffs both north and south of the river, and extends as far west as Mountain View. Ledges which probably belong to the same general horizon outcrop north of the Wichita Mountains in the vicinity of Hobart and Harrison, and it is not impossible that further studies may demonstrate that the same beds extend under the upper gypsums across Greer County.

"'*Day Creek dolomite.*—Resting upon the upper part of the Whitehorse sandstone in Kansas and Oklahoma is a conspicuous ledge of hard, white dolomite, first described by Professor Cragin from exposures in southern Kansas, as follows:[a]

"'Upon the latest of the Red Bluff rests a persistent stratum of dolomite varying in thickness from less than a foot to 5 feet or more. * * * It is true dolomite, containing with the carbonate of lime an equal or even greater percentage of carbonate of magnesia. Though not of great thickness, it is an important member of the upper Permian of southern Kansas and northern Oklahoma, owing to its persistence, which makes it a convenent horizon of reference. * * * The stone is nearly white in fresh fracture, weathering gray, and often has streaked and gnarly grain resembling that of fossil wood. * * * Is cherty hardness and fracture are not due to the presence of silica, as one is tempted to infer, but are characters belonging to it as a dolomite. It is a durable building stone.'

"In his second paper on the Permian rocks, in describing a typical Oklahoma locality, Professor Cragin says:

[a]Op. cit., p. 44.

" 'The brow of the Red Hills near Watonga, Okla., is capped with the Day Creek Dolomite, which here presents itself as a compact stratum of gray, somewhat pinkish or reddish tinged cherty-hard rock, little different from the typical ledge that skirts the flanks of Mount Lookout in Clark County, Kans. The stratum here has a thickness of 3 feet.'

"The line of outcrop of the Day Creek in Oklahoma is not continuous; nevertheless, it is found in numerous localities, and on account of its distinctive lithological appearance it is always easily recognized. It is displayed on many of the hills of Woodward County, not only north of the Cimarron, but also between the Cimarron and the North Canadian and south of the latter stream. In Blaine County it forms the caps of a number of the prominent hills, notably the Red Hills between Geary and Watonga. South of Canadian River in Caddo County the dolomite covers the Whitehorse buttes southwest of Bridgeport and outcrops southwestward as far as the headwaters of Cobb Creek and on the west side of that creek past Colony. In the vicinity of Mountain View, in the valley of Washita River, a ledge of dolomite appears at the same general level as that occupied by Day Creek, and another dolomite ledge in the hills north of Harrison may provisionally be referred to this horizon.

The composition of this material in Oklahoma may be understood by reference to the following analysis:

Analysis of dolomite from the summit of the Red Hills 6 miles northwest of Geary, Okla.

	Per cent.
Calcium carbonate	42.47
Magnesium carbonate	52.86
Water	1.82
Oxides of iron and aluminum	1.35
Silica and insoluble residue	1.82
Total	100.32

Greer formation.

The Greer formation outcrops in two areas. The eastern one begins in the southeast corner of Woodward County and

extends east of south in a widening belt through the central part of Dewey and Custer Counties and eastern Washita County. In the southeastern part of Washita the belt divides, one branch swinging more to the east through the southwestern parts of Caddo and Grady Counties into northwestern Stephens County. The other swings west along the south line of Washita County and is thought to connect with the western area in Beckham and Greer Counties, although the connection cannot be made out on account of the covering of alluvium and sand in the valley of North Fork of Red River. The western area of the Greer occupies all of Harmon, southern Beckham, western Greer, and western Jackson Counties.

The Greer formation is made up of sandstones, shales, and gypsums, with a ledge of dolomite, having a total thickness of about 150 to 300 feet. The stratification in the eastern area is extremely erratic and no horizon can be traced sufficiently far to be used as a basis for separating the formation into members. The gypsums are lenticular and in the northern part of the area are few in number and not very thick; to the south the gypsum lentils become more numerous and thicker, reaching their maximum in eastern Washita County. Farther southeast the ledges thin out.

In the western area the stratification is more regular and five distinct beds of gypsum and one of dolomite can be traced for considerable distances and are classed as members of the formation.

Quartermaster Formation.

As is the case with the Woodward formation, the Quartermaster contains no important deposits of gypsum in Oklahoma and little attention was paid to it in the field work for this report, and the writer has no facts concerning the formation to add to those already published by Gould[75]. Consequently his description is given in full.

"Above the Greer are 300 feet or more of soft, red sandstones, and arenaceous clays and shales, to which the name Quartermaster has been applied. So far as known this is the highest formation of the Redbeds in Oklahoma.

[75]Gould, C. N., Op. cit., pp. 72-73.

"In the lower part of the formation the rocks are chiefly shales, typically red, but sometimes containing greenish bands and layers. The shales become more arenaceous above, and in places form a strong, consolidated sandstone, which is rather thin bedded and prone to break into small rectangular blocks, and weather queerly into long and narrow buttresses or rounded, conical, or nipple-shaped mounds from 10 to 50 feet or more high. These mounds may be solitary, but in some areas hundreds of them occur in a single quarter-section. The sandstone is further characterized by the marked and very peculiar dip of the rocks in certain directions. The strata often dip at angles of from 20° to 40° to all points of the compass, even in a small area. These dips often produce escarpments that have the appearance of those formed by regularly bedded dipping strata. The most plasible explanation of this phenomenon is that the erratic dipping is caused by the undermining of deep-seated rocks, probably some of the various gypsum members of the Greer.

In this sandstone, particularly in its upper part, there are many springs of soft water, which usually issue as seeps at the head of deep canyons or beneath bluffs of red sandstone. While few of them have large flows, many are large enough to supply farmhouses, or, in some cases, to furnish stock water for ranches. Wells in these sandstones frequently yield good water at moderate depths. In fact, with the exception of the eastern area of the Enid, the Quartermaster is the only Redbeds formation in which any large amount of good water is found.

"Except where covered by younger rocks, the Quartermaster outcrops over practically all of Day and Roger Mills counties [Ellis and Roger Mills], and is also extensively developed in the western part of Dewey, Custer, and Washita counties. To the south and east it is underlain by the Greer, while to the west and north it disappears beneath the sands of the Tertiary. Streams tributary to the South Canadian, Washita, and the North Fork of Red River in the region form canyons in this rock and are fed by springs issuing from it. The name is from Quartermaster Creek, which bows from Day County through the extreme northwestern corner of Roger Mills County and empties into Washita River in Washita County. Along this creek both the lower shales and the sandstones higher up in the formation are well exposed.

The peculiarities of structure and weathering are also well exemplified along this stream. In the present state of our knowledge it is not deemed advisable to attempt to subdivide the Quartermaster formation."

CHAPTER V.

NATURE, OCCURRENCE AND DEVELOPMENT OF THE GYPSUM OF OKLAHOMA.

In the previous chapter it was shown that the commercial gypsum deposits of Oklahoma occur in two distinct formations, the Blaine and the Greer. In this chapter the nature of each of these formations is discussed in as much detail as the present state of our knowledge will permit. The two papers by Gould[76] are used extensively and several of the sections and analyses given in the second report of the Territorial Survey are presented in full in connection with the description of the various localities. The field notes of Frank A. Herald and C. C. Clark, who spent the field season of 1907 in the study of portions of the gypsum deposits, are used wherever possible. The field work of the writer occupied 10 weeks in the autumn of 1912, during which time he was assisted by Jerry B. Newby.

Following Gould the gypsum area is divided into four general areas: (1) the Kay County area, (2) the main line of gypsum hills, *i.e.* the outcrop of the Blaine formation, (3) the second line of gypsum hills or the eastern area of the Greer formation, and (4) the southwestern area. The name Greer County Region was given to the last area when Greer County included what is now Jackson and Harmon counties and a part of Beckham County. The present Greer County contains only a portion of the area so it is thought best to change the name. The areas or regions will be taken up in the order named.

[76]Gould, Chas. N., Oklahoma gypsum: Second Bien. Rept. Okla. Dept. Geol. and Nat. Hist., 1902, pp. 87-120; Geology and water resources of Oklahoma: Water-Suply Paper U S. Geol. Survey No. 148. 1904, pp. 44-52 and 59-72.

KAY COUNTY AREA.

The Kay County area is outside the Redbeds region gypsum occurs in non-red Permian rocks at or near the of some of the important gypsum deposits of Kansas. Th sum is not pure but occurs mixed with clay as gypsite. was operated in this area for awhile some years ago known supply of material was exhausted and the mill re This locality was not visited in connection with the prep of the present report and Gould's description[77] is given in

"In the central part of Kay County, Oklahoma, region between Newkirk and Blackwell, along the various Duck, Bois d'Arc, Bitter and others that flow south in Salt Fork, there are a number of local deposits of gyp gypsiferous earth. As a usual thing these deposits are no extensive. However, they are of sufficient importance th of the four plaster mills in the territory is located ther supply of material is obtained along one of the branches of creek.

"The region is slightly rolling. The creeks have out broad and shallow valleys in the level prairie. The of Duck creek is from one to two miles wide and not ov feet deep, sloping gently from the upland to the creek bed. higher land is prairie and a few trees grow along the creek. Th rocks in the country are gray and bluish clays and shales with a few ledges of soft, impure limestone. Few rocks of any kind, however, are exposed, the greater part of the country being practically level prairie with few breaks or washes. It is near the creek bank on a gently sloping surface that the gypsum used in the mill is obtained. The deposit covers several acres, and has been worked out in places to the depth of ten feet or more.

"The Kay County deposits belong to the Marion formation of the Permian. The Marion formation extends from central Kansas south through Marion, Harvey, Butler, Sedgwick, Cowley and Sumner counties. The rocks are soft shale and clays, gray to blue in color, with a few beds of impure gray limestones. Gypsum deposits are not uncommon. Plaster mills have been

[77] Gould, Chas. N., Oklahoma gypsum: Second Bien. Rept. Okla. Dept. Geol. and Nat. Hist., 1904, pp. 87-88.

ıted in this formation at several points in Kansas, notably at rns and Mulvane. Other deposits are known to exist in But- and Sedgwick counties and in the vicinity of Geuda Springs. general, however, the deposits are local and quite limited in ount. The experience has been that a mill located on this for- tion will use up its supply of available material in a few rs and will be compelled to move.

"Whether or not there are gypsum deposits of any magni- e along the line of this formation further south than Kay ınty is not known. Occasionally a deposit is reported from region, but on investigation it has usually proved to be very ited, and for that reason of no particular economic import- e. South of Kay County the blue and gray shales of the rion formation change into typical Red-beds. Now the Red- s throughout are more or less gypsiferous. But in general gypsum is so thoroughly disseminated throughout the rock t it can never be utilized. Its presence, however, is demon- ıted by the character of the water in these rocks.

"Above the level of the Kay County gypsum there is a thick- s of about 1000 feet of red rocks. These rocks, which make the lower part of the Oklahoma Red-beds, consist chiefly of rs, shales and a few beds of soft sandstones. They occupy level country in eastern and central Oklahoma between the of the Santa Fe railroad and the main line of the gypsum s. There are in this region a few small gypsum deposits. ı number of localities farmers dig gypsum from a bank, burn nd use the product for plaster and mortar. That the rocks he region are thoroughly permeated with gypsum and other ıeral salts is demonstrated by the fact that the water of the t of the region is so strongly impregnated with the various s as to render it in many instances unfit for drinking."

MAIN LINE OF GYPSUM HILLS.

INTRODUCTION.

The general description of the Blaine formation has been en in the previous chapter. In this connection it is necessary repeat a few of the principal features. The formation con- s of three gypsum members (the Ferguson, Medicine Lodge, l Shimer) separated by red and green shales. The outcrop is

a pronounced eastward and northeastward facing scarp above the soft, red shales of the Enid formation. Buttes and peculiar erosional features are very common. The outcrop enters the State from Kansas on the south side of the Salt Fork or Arkansas River and follows down that stream for a few miles, swings back along the north side of the Cimarron, crosses that river near the Kansas line, and extends down the south side, gradually getting farther away from the stream until the gypsums and the hills die out in northern Canadian County.

In the following discussion the description of this range of hills is given in detail by counties, commencing with Woods County at the northwestern limit of the hills in Oklahoma. Before describing the Woods County area the Grimsley's description of the northern extension of the hills in Kansas is given.

THE GYPSUM HILLS IN KANSAS.

"The gypsum of the Medicine Lodge area is entirely rock gypsum, is white in color, and in the lower portion of the strata is very compact. This portion is used at the Medicine Lodge mill for the manufacture of *terra alba*. The upper portion has more of the sugary texture and is used in the manufacture of wall plaster. The satin spar which is found throughout the Redbeds below the gypsum is in the form of wavy plates, with perpendicular needles, and variable in character. Some of it is soft, and readily crumbles, while other portions are compact and glassy in appearance.

"*Extent of the area.*—This southern gypsum area is the largest in Kansas, and, with its continuation in Oklahoma and Texas, forms the largest gypsum area in the United States. The rock extends from near the town of Medicine Lodge westward through Barber and into Comanche County, southward into Oklahoma and Texas, and passes under the Tertiary gravels to the north. The trend of the outcroppings of the deposits is the characteristic one of the state, northeast to southwest.

"The gypsum is first seen six miles southwest of Medicine Lodge, in an isolated range of hills three miles long and separated by a narrow valley from a second hill one mile in length

[a]Grimsley, G. P., Gypsum and gypsum cement plaster: Univ. Geol. Survey of Kans., vol. 5, pp. 70-73.

: valleys of East and West Cedar creeks, two miles wide, sep-
te these hills from the next series, in which the gypsum plat-
is continuous to the west. Medicine Lodge river cuts the
sum in a valley six or seven miles wide. The northern limit
;he gypsum cannot be determined, for it is covered with Ter-
y deposits. Salt Fork and Sandy creeks cut out broad val-
s to the south, and the streams in the eastern portion of
nanche county have removed much of the stratum; but the
)sum is continuous over the greater portion of western Bar-
and eastern Comanche counties. * * *

"In the eastern part of Comanche county, on Cave creek a
ond gypsum layer 15 feet thick is found, 15 feet above the
dicine Lodge layer. This upper layer was called the 'Shimer
)sum' by Cragin. It appears to be a local deposit.

"*Geological relations.*—Looking west from the town of
dicine Lodge one can see in the distance a range of hills of
sion with sloping sides and level tops. These hills extend in
north and south direction and are called the Gypsum Hills.
e sides are composed of the red clays and shales of the Red
ds, the age of which is still somewhat uncertain, but they
obably belong to the Permian. The cap rock is a ledge of
id gypsum, which has protected to a considerable extent the
derlying, softer strata.

"At the base of the hills is a massive red sandstone. A sec-
d red sandstone is found 125 feet higher, and 100 feet above
is comes a ledge of gypsum forming the top of the hills. This
psum layer varies from 3 to 20 feet in thickness, depending
the amount of erosion. Forty feet below the gypsum is a
een gypseous sandstone 2½ feet thick, which stands out as a
ominent ledge through the hills. The red clays and shales
ntain an interlacing network of selenite and satin-spar layers
variable thickness. This material has been dissolved out of
ie solid stratum and carried downward through the agency of
rculating water and redeposited. * * *

"*Solution effects.*—In the western part of Barber and the
astern part of Comanche counties the solvent effects of water
n gypsum are well shown. On Cave creek, four miles west of
Evansville, is the Big Gypsum cave in the Medicine Lodge gyp-
um. A stream of considerable size flows into the west entrance
nd out of the east one, making the cave, in reality, an under-

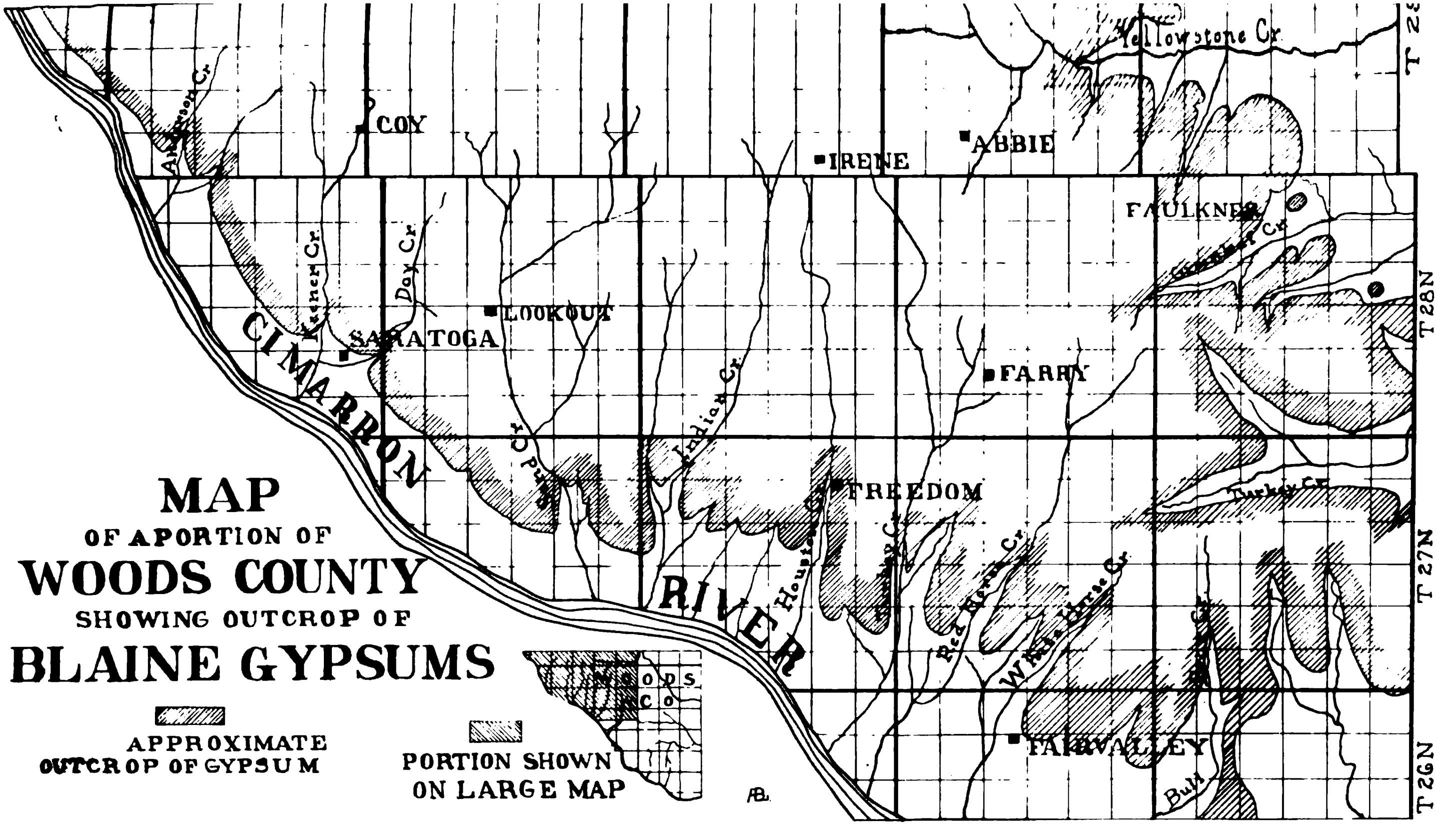
ground water course. The length of the cave is at least 100 feet with a roof at the east entrance 15 feet above the water level, but which soon narrows down to a height of 3 feet. The floor is strewn with large slabs of white gypsum. At the center is an opening through the roof to the sky above. This hole is a ... feet in diameter in the cave and 30 feet on the surface and nearly circular. The western half of the cave is low and the floor is muddy and covered with water so as to be almost impassable. The section near this cave shows 30 feet of the Medicine Lodge gypsum separated by 15 feet of red shale from the Shimer gypsum, which is 15 feet in thickness. This is the typical exposure of the Cave Creek formation of Cragin.

"The natural bridges found here represent remnants of caves of underground water channels whose roofs have partly fallen in. One of the best of these natural bridges is found on Bear creek south of Sun City. * * *"

WOODS COUNTY.

Area of outcrop.—The Blaine formation makes a crescent shaped outcrop in the Western part of Woods County, and is principally in the portion of the county which belonged before 1907 to Woodward County. The approximate outcrop of the formation is shown on the map (fig. 31). The line of hills crosses the Kansas-Oklahoma line near the east side of R. 17 W. —the old Woods-Woodward county line. The line of the base of the Blaine extends east into R. 16 W. about 1½ miles, then swings south and back west along the north side of Yellowstone Creek as far as Kingman. Here the gypsums cross the creek and follow down the creek on the south side for about five miles, then in a general course to the south until they reach a point about 8 miles west of Avard where they swing back to the northwest on the north side of Cimarron River. The eastward facing escarpment is irregular, the two main indentations being caused by Greenwood (Greenleaf) and Turkey (Moccasin) creeks which have cut canyons back into the gypsums for 5 or 6 miles. There are many minor irregularities and several outliers or buttes, some especially fine ones near where Greenwood Creek leaves its canyon in the vicinity of Faulkner.

Northwest from Fair Valley the bluffs are almost 2 to 3 miles back from the river until within a few miles of the Kansas


MAP
OF A PORTION OF
WOODS COUNTY
SHOWING OUTCROP OF
BLAINE GYPSUMS
APPROXIMATE
OUTCROP OF GYPSUM
PORTION SHOWN
ON LARGE MAP
CIMARRON
RIVER
COY
IRENE
ABBIE
FAULKNER
LOOKOUT
SARATOGA
FARRY
FREEDOM
FAIRVALLEY
Yellowstone Cr.
Kesner Cr.
Day Cr.
Indian Cr.
Houston Cr.
Red Horse Cr.
White Horse Cr.
Turkey Cr.
Bull
WOODS
CO
T 28N
T 27N
T 26N
AB.

line where they come within one-half mile or less of the river. The gypsums cross the river just north of the State line and then swing back on the south side through Harper and Woodward counties. On the Woods County side of the river 8 creeks flow in from the northeast and enter the Cimarron almost at right angles. These are named in order from east to west: White Horse, Red Horse, Turkey, Houston, Indian, Sand, Keener, and Anderson. Each of these, as well as many minor runs, has cut a canyon or gully back into the gypsum upland. The canyons of the streams named are from 2 to 5 miles long and usually less than one-half mile wide at their widest parts. The width of the outcrop varies from a fraction of a mile at the head of the canyons and on some of the very steep slopes, to 2 or 3 miles on some of the long hills between the canyons. Beginning a few miles east of Saratoga and continuing to the Kansas line is a belt in which sand from the valley is blown up over the hills, sometimes covering them to a depth of several feet and obscuring the lines between the Blaine and the formations above and below.

Stratigraphy.—Where the hills cross the Kansas-Oklahoma line 3 gypsum ledges show on the slopes, and these are apparently continuous throughout the outcrop in Woods County. All 3 ledges are entirely selenitic and, as has been mentioned in a previous chapter, the effects of solution by ground water are much more pronounced in the selenitic than in the fine-grained rock gypsum. Sink holes are common and there are several caves, some of them of considerable extent as, for instance, the Bat Cave near Kingman. The slopes of the hills are less abrupt and the crests are more rounded than is the case farther southeast in Blaine County. The fresher exposures show the interlocking network of selenite crystals, but the weathered exposures show a white, powdery mass, sometimes with the outlines of the crystals remaining but often without any trace of them. This white earthy material when mixed with a clay sometimes bears resemblance to gypsite but can be easily distinguished from it by its structure and whiter color.

Often a whole ledge will be dissolved for some distance back into the hill and only 2 or perhaps 1 ledge will show on the side of a hill. In other localities the soft shales seem to "creep" and large blocks of gypsum break from the ledge and slip a few feet down the slope and thus give the appearance of another ledge.

nere one of the lower ledges is absent by solution, the shales d the upper ledges may settle down into the cavity so formed, d this gives rise to an appearance of folding. This is often own in Woods County, but is not so pronounced as across the marion in Harper County. (See fig. 35.) Some of the effects solution and also the character of the gypsum in this region shown in figure 32. This is really a small natural bridge as

Fig. 32. Outcrop of selenitic gypsum near Kansas line northwest of Winchester.

there is a small sink hole opening just back of where the man is sitting. The outlines of the selenite crystals are fairly well shown about the middle of the ledge.

The absence, by solution, of the ledges in some places and the duplication of ledges by slip in other places make the determination of the stratigraphy difficult. On the clearer exposures, however, there seem always to be 3 ledges of gypsum of which the lowest is much the thickest, while the middle and upper are of approximately equal thickness. The lower and middle are separated by only a few feet of shale and may sometimes coalesce, while the middle and upper are separated by an interval of some 15 feet. The succession is fairly well shown in the following section:

Section on Yellowstone Creek 1½ miles southeast of Kingman in W. ½ sec. 24, T. 29 N., R. 17 W.

		Feet
6.	Gypsum (Shimer) top eroded	8
5.	Covered, probably green and red shale	12
4.	Gypsum (Medicine Lodge)	[illegible]
3.	Covered, probably green and red shale	7

Fig. 33. Canyon of Yellowstone Creek near Kingman.

. Gypsum (Ferguson) 18
. Covered, probably shale.......................... 34

The canyon where this section was taken is shown in figre 33.

While the section is not sufficiently clear to prove absolutely he presence of 3 gypsum members, the abrupt changes of slope etween the different members, and the difference in vegetation nd in expression leave very little doubt that the three are resent.

If the three gypsums are present the names to be applied to hem are somewhat in doubt. According to Gould[79] the lowernost gypsum member as exposed in Blaine Couptny (the Ferguon) disappears in the vicinity of Glass Mountains in Major County and he makes no mention of its reappearance. Only the Shimer and Medicine Lodge are mentioned as occurring in Kanas. The evidence is so strongly in favor of the presence of hree ledges throughout Woods County, and on the opposite side f the Cimarron, however, that the writer is compelled to beieve, (1) either that the Ferguson is present, or (2) that a new edge has appeared in its place or between the Medicine Lodge nd the Shimer.

The question is interesting from a stratigraphic standpoint ut is of no importance on the economic side. Therefore in this eport the hypothesis that where three ledges are present the owest represents the Ferguson is accepted merely as a working basis. In other words, where three ledges are present they are called, from the bottom up, the Ferguson, Medicine Lodge, and Shimer, and where two are present, the Medicine Lodge and Shimer. Detailed mapping may prove it necessary to make considerable change in the naming of these gypsums.

Availability and development of the gypsums.—The amount of gypsum present at a reasonable depth in Woods County is very great, ample to supply a large number of mills for an indefinite length of time. At present however, all of it is so far removed from a railroad that it cannot be considered available. Preliminary surveys for the Winnepeg and Gulf Railroad have been run through the gypsum area and if the road should be

Gould, Chas. N., Geology and water resources of Oklahoma: Water-supply paper U. S. Geol. Survey No. 148, 1904, p. 46.

built through this region it will render large deposits accessible. In case this gypsum should become accessible, and an attempt should be made to develop it, the proposed sites for mills should be very carefully prospected, on account of the irregularity of occurrence of the ledges, due to solution, No use is being made of any of the gypsum in Woods County. The mill of the Oklahoma Plaster Company is located at Alva but uses gypsum from near Quinlan in Woodward County. The mill is described in chapter II and the quarry under Woodward County in this chapter.

HARPER COUNTY.

Area of outcrop.—The Blaine formation crosses the Cimarron just north of the Kansas line and then follows down the stream on the southwestern side. For several miles it forms a narrow belt along the southwestern bank, with only a few narrow canyons extending as far as two miles back from the line of bluffs, until Buffalo Creek is reached in the southern part of T. 21 N., R. 20 W. This creek flows in a narrow canyon in the gypsums from about five miles southwest of Charleston, almost due east until it enters the river. The canyon is narrow, not

Fig. 35. Folding of gypsum ledge due to solution of underlying ledge, near mouth of Sand Creek, Harper County.

exceeding a mile in width until very near the Cimarron. On the north side of the creek there are only a few minor irregularities in the outcrop, but on the opposite side, Race Horse, Sand, and Sleeping Bear creeks carry the outcrop back to the south a few miles. The width of the outcrop varies from less than a mile to four or five miles. The line of hills leaves the county south of Buffalo Creek in T. 27 N. The approximate area of the outcrop of the formation is shown on the map (fig. 33).

Stratigraphy.—In general the stratigraphy of the Blaine formation in Harper County is the same as in Woods County across the Cimarron. Where clear exposures are had there seem to be three gypsums but on slopes, one or more of these may fail to appear. All of the gypsum is selenitic. The effects of solution are prominent. The solution of the lower ledges often causes the upper ones to appear folded. A synclinal fold of this sort is shown in figure 35.

Duplication of outcrop by slip also appears to be of common occurrence. A rather peculiar structure which is interpreted in this way is shown in the north bank of Buffalo Creek below its junction with Sand Creek (fig. 36).

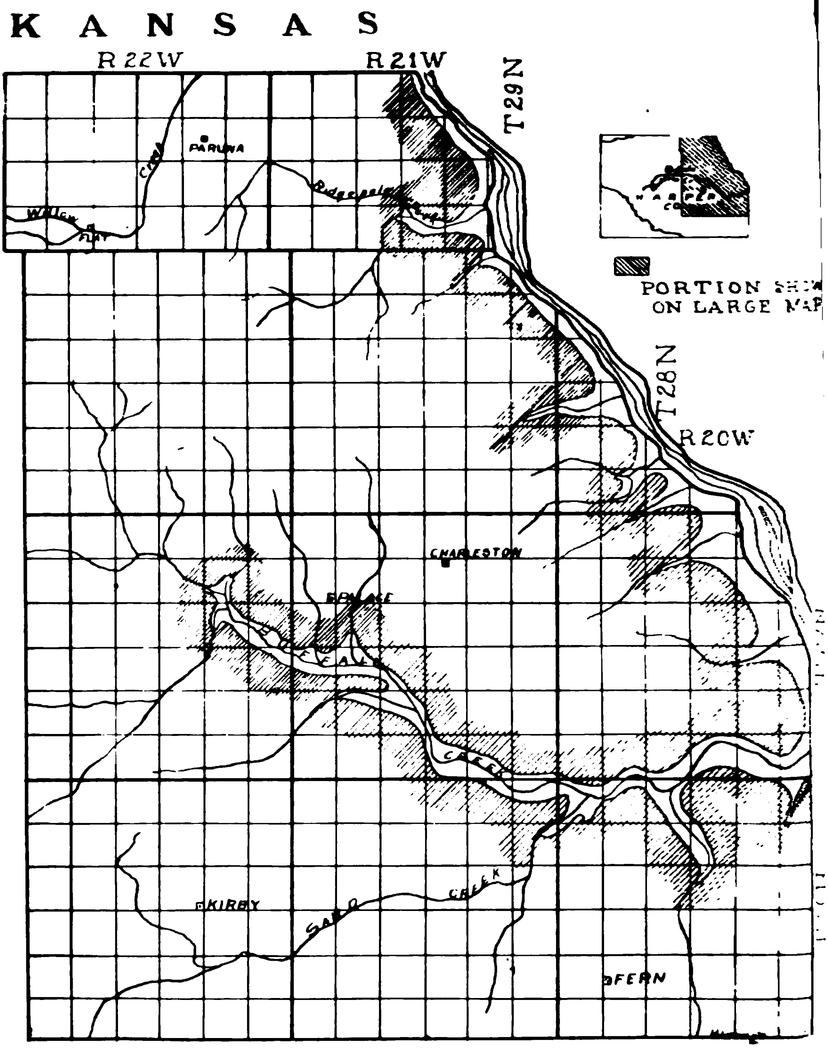
Good sections of the Blaine are very rare in this county. Probably the best exposure is near the Big Salt Plains on the Cimarron where the following section was measured by Gould.[80]

Section at southeastern corner of Big Salt Plain in Harper County.

		Feet.
5.	Red clay to top of bluff	15
4.	Massive white gypsum, the Shimer	15
3.	Red clay	10
2.	Massive white gypsum, the Medicine Lodge	24
1.	Red clay, with bands of selenite and gypsum concretions from the level of the plain	80

The general appearance of the outcrops leads the writer to the conclusion that No. 2, the Medicine Lodge, of Gould's section is usually composed of two members separated by a shale which

[80]This section and those following which are attributed to Gould are from the Second Biennial Report of the Oklahoma Department of Geology and Natural History, unless otherwise specified.



MAP
OF A PORTION OF
HARPER COUNTY
SHOWING OUTCROP OF
BLAINE GYPSUMS

APPROXIMATE OUTCROP OF GYPSUM

Fig. 36. Duplication of outcrop of gypsum ledge due ot slip. Buffalo Creek below Sand Creek, Harper Couny.

ranges up to seven feet in thickness locally, and that it probably represents both the Ferguson and the Medicine Lodge. The total thickness of gypsum as given in the section seems to hold fairly well for the area in this county.

Availability and development of the gypsums.—The gypsums of Harper County are well exposed for quarrying and the amount which can be obtained is very great, estimated by Gould[81] at 10,000,000,000 tons. Several locations along the Cimarron and along Buffalo Creek and its tributaries furnish good situations for quarries if transportation facilities were at hand. At present, however, the deposits are so far from railroads that there is no possibility of their development in the near future, even if all other conditions were favorable.

WOODWARD COUNTY.

Area of outcrop.—The outcrop of the Blaine formation en-

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[81]Gould, Chas. N., Structural materials of Oklahoma: Bull. Okla. Geol. Survey No. 5, 1911, p. 105.

ters Woodward County from Harper in T. 27 N., R. 19 W., continues down the Cimarron in a belt two to five miles in width and passes into Major County on the line between Ranges 16 and 17 W., T. 23 N. Several creeks have cut canyons back into the gypsum indenting the outcrop and carrying it back to the southwest. These creeks are, from west to east, Traders, Girl, Long, Doe, Chimney, and West creeks. The approximate area of the outcrops is shown on the accompanying map (fig. 37).

Stratigraphy.—The stratigraphy of the gypsums in this county is practically identical with that in Woods County on the opposite side of the Cimarron, and in Harper County to the northwest, which have already been discussed. In several places the Ferguson is apparently absent and the Medicine Lodge forms the crest of the hills and buttes. The hills are very rugged and the canyons are deep and steep sided. Many peculiar erosional forms have been developed due to the capping of the very soft sands and clays of the Enid by the relatively resistant gypsum. One of the most striking of these is Chimney Butte, from which Chimney Creek takes its name (fig. 38). The gypsum is entirely removed from this butte but several in the vicinity are capped by gypsum. Mt. Heman and Mt. Zion are large buttes near Heman in the northeastern part of the county.

At this locality the Medicine Lodge seems to be the lowest gypsum and just west of Chimney Butte, (sec. 27, T. 25 N., R. 17 W.) boulders of anhydrite up to five feet in diameter were noticed about the middle of the layer of gypsum. This is the first observed occurrence of a feature which becomes very prominent to the southeast. Lentils 10 to 20 feet long and three feet in thickness occur in the Medicine Lodge near the Woodward-Major County line in sec. 24, T. 23 N., R. 17 W. At this locality all three gypsums are shown. The dolomitic sandstone beneath the Shimer is about three feet thick.

The stratigraphy is shown in the following sections by Gould.

Section made at the high bluff at the southeast corner of the Salt Plain.

		Feet.
5.	Red clay to top of bluff	15
4.	Massive white gypsum, the Shimer	15

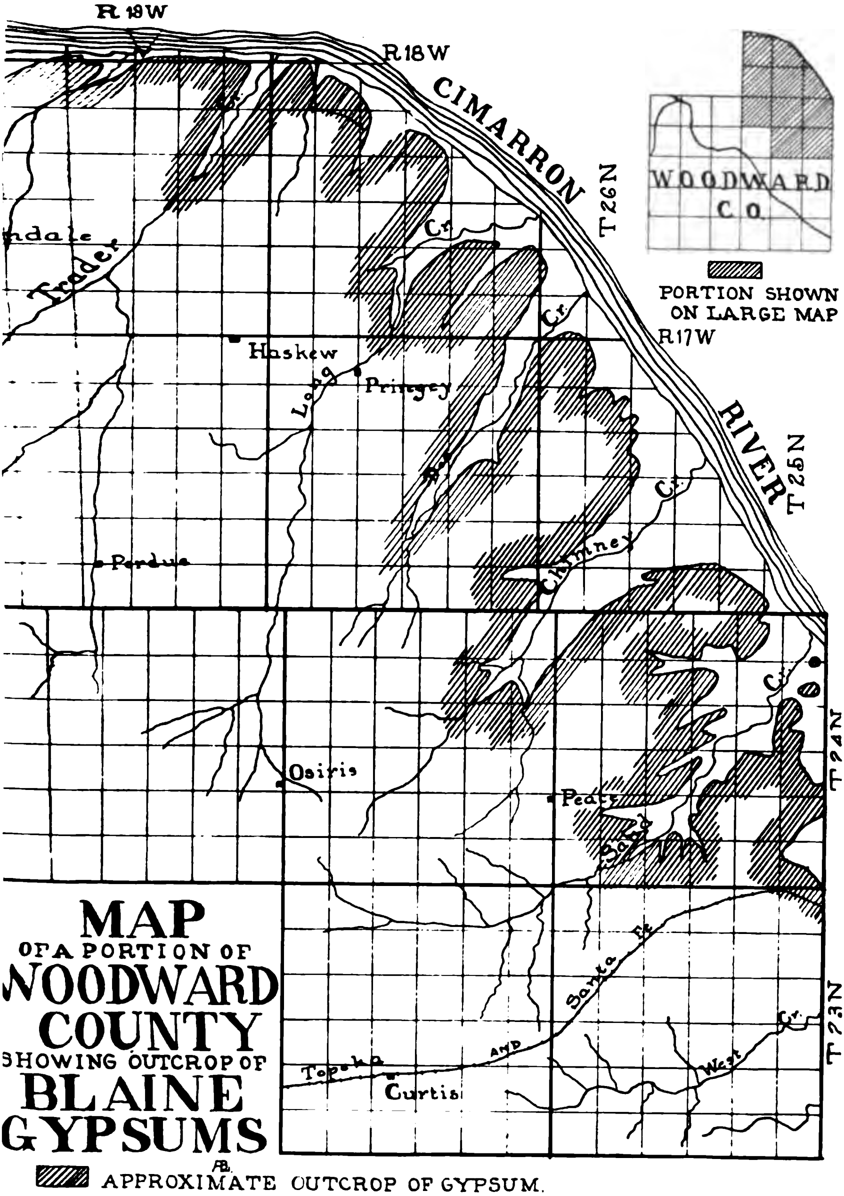

R 19 W
R 18 W
CIMARRON
RIVER
T 26 N
T 25 N
T 24 N
T 23 N
R 17 W
WOODWARD CO.
PORTION SHOWN ON LARGE MAP
Trader
Cr.
Haskew
Long
Pringey
Perdue
Chimney
Osiris
Peats
Sand
Santa Fe
Topeka AND
Curtis
West
MAP OF A PORTION OF WOODWARD COUNTY SHOWING OUTCROP OF BLAINE GYPSUMS
APPROXIMATE OUTCROP OF GYPSUM.

Fig. 38. Chimney Butte.

3.	Red clay	10
2.	Massive white gypsum, the Medicine Lodge	24
1.	Red clay, with bands of selenite and gypsum concretions from the level of the plain	80
		144

Section made on a butte at the mouth of Doe Creek, Woodward County.

		Feet.
4.	Massive, white gypsum, the Shimer	25
3.	Red clay	5
2.	Massive, white gypsum, the Medicine Lodge	30
1.	Red clay and shale slope from the river	200
		260

Section made on Sand Creek five miles northeast of Quinlan.

		Feet.
5.	Red clay with local deposits of gypsum	75
4.	Massive, white gypsum, the Shimer	22
3.	Red clay	7
2.	Massive white gypsum, the Medicine Lodge	30
1.	Red clay from creek bed	120
		254

Availability and development of the gypsums.—The Atchison, Topeka & Santa Fe Railway crosses the line of gypsum hills between Quinlan and Belva in the extreme eastern portion of the county. A great amount of gypsum is available from this line. Up to the present the only development is the quarry of the Oklahoma Plaster Company whose mill is located at Alva. The quarry is located in sec. 10, T. 23 N., R. 17 W., and has been worked out over an area of about one acre. The lowest ledge is quarried. It is about fifteen feet thick and is composed of selenitic gypsum. The bed is cut by vertical funnel-shaped solution channels, varying in size from a few inches to a foot or even more in diameter. The solution channels and joint cracks, which are usually enlarged by weathering, are filled with red clay. The gypsum is shot from the ledge in the ordinary way and the small blocks loaded into dump cars and pushed by hand to a loading trap over the railroad switch.

The amount of gypsum available in this region is sufficient to supply several mills if commercial conditions were such as to justify their construction. The total amount of available gypsum in the county according to Gould's estimate is 8,000,000,000 tons.

MAJOR COUNTY.

Area of outcrop.—Where the line of hills enters Major County from Woodward it is near the Cimarron but it gradually drops back to the south until at Fairview the foot of the main

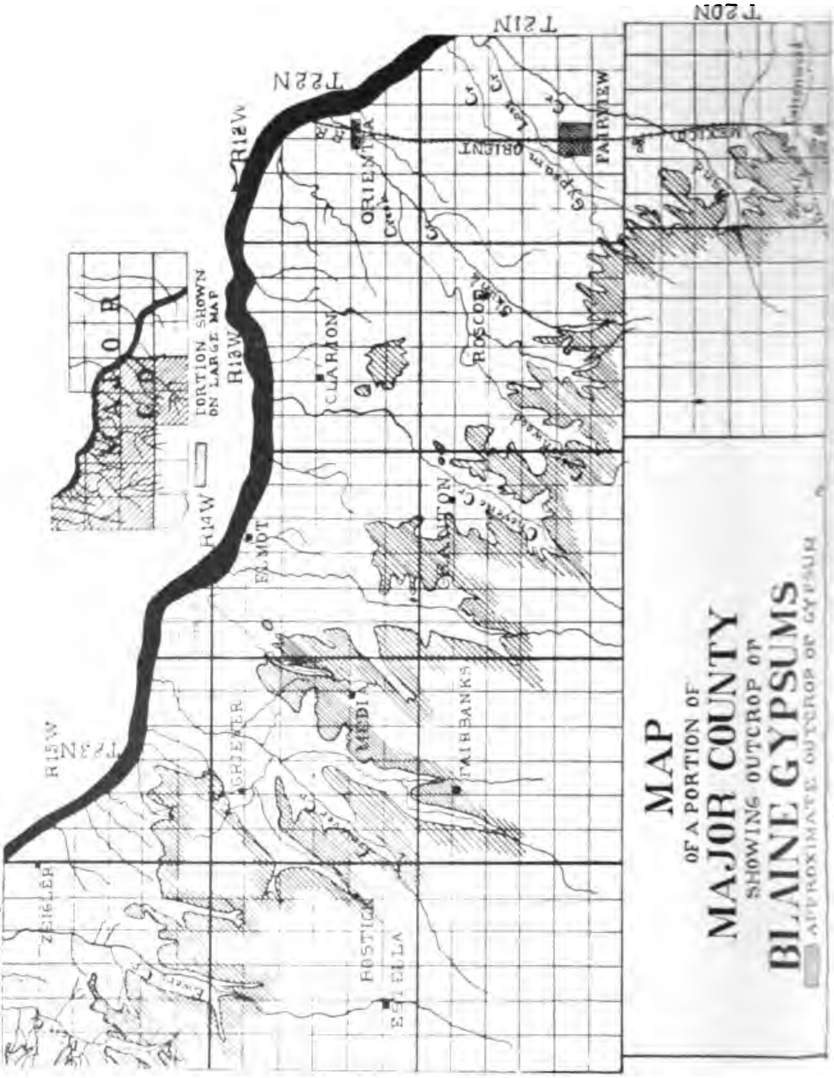


Fig. 39.—Map of a portion of Major County showing outcrops of Blaine Gypsum.

body of the hills is ten miles or more from the river. At Fairview the line of hills leaves the river and turns almost directly south and continues in this direction into Blaine County. The approximate outcrop is shown on the accompanying map (fig. 39).

The outcrop is very irregular and is indented by several creeks. The principal streams from west to east are: West, Main or Ewers, Crooked, West Griever, East Griever, West Barney, Barney, Cheyenne or Skull, Cottonwood, and Gypsum creeks.

Stratigraphy.—In the western part of Major County the three gypsums seem to be present with about the same thickness and separated by approximately the same intervals as to the northwest. These relations are shown by the following sections:

Section at head of Crook Creek Canyon in sec. 14, *T.* 22 *N., R.* 16 *W.*

		Feet.
5.	Shimer gypsum	10
4.	Red and green selenitic shales with some sandstone	15
3.	Medicine Lodge gypsum	15
2.	Red and green selenitic shales with dolomitic sandstone	10
1.	Ferguson gypsum	15

All three gypsums are shown plainly but the contracts are not exposed so that the thicknesses given are approximations. The gypsum is almost completely selenitic.

Section of east side of East Griever Creek Canyon in sec. 28, *T.* 22 *N., R.* 15 *W.*

		Feet.
12.	Medicine Lodge gypsum	16
11.	Greenish sandstone	1
10.	Red and green gypsiferous shale	8
9.	Ferguson gypsum	15
8.	Greenish, shaly sandstone	1
7.	Green shale, very selenitic	1½
6.	Greenish dolomitic sandstone	¼
5.	Red shale with bands of green shale and satin spar	26
4.	Shaly, cross-bedded, selenitic sandstone	7

3.	Red shale, with bands of green shale and satin spar..	6
2.	Shaly, cross-bedded, selenitic sandstone............	1
1.	Red shale containing many thin bands of green shale and satin spar from East Griever Creek..........	93

Farther back on the hill and about 20 feet above the Medicine Lodge gypsum is a heavy, honey-combed sandstone that occurs just below the Shimer gypsum throughout this region.

The anhydrite in the Medicine Lodge is present only in thick short lentils. One of the lentils a few feet north of where this section was made is over five feet thick at the middle and about eight feet long. These lentils occur at irregular intervals and at different horizons on the bed. The beds are made up chiefly of selenite crystals.

In sec. 22, T. 22 N., R. 15 W., the Ferguson gypsum shows a thickness of fifteen feet and is underlain by ten inches of greenish dolomitic and selenitic sandstone.

Section on West Barney Creek in sec. 25, T. 22 N., R. 15 W.

		Feet.
13.	Shimer gypsum	8
12.	Honey-combed dolomitic sandstone................	2
11.	Covered, probably shale.........................	17
10.	Medicine Lodge gypsum...................about	10
9.	Covered, probably shale.........................	13
8.	Ferguson gypsum	11
7.	Greenish dolomitic sandstone....................	½
6.	Green, sandy shale............................	3½
5.	Red shale with many thin bands of green shale and satin spar	14
4.	Selenitic sandstone	½
3.	Red and green shales...........................	8
2.	Shale and soft sandstone, red and green, cross-beeded, gypsiferous	8½
1.	Covered, probably shale.........................	41

In this section there are no good exposures of the top of the Ferguson or of either the top or the bottom of the Medicine Lodge. The top of the Shimer is eroded. The thickness of the gypsums as given in the section represent what is actually exposed. The anhydrite in the Medicine Lodge seems to be a continuous body over six inches thick. The upper portions of

all three ledges are very selenitic, that of the Shimer especially so. The lower portions of the ledges have taken on the fine-grained condition which is common to all of the gypsum a few miles farther to the southeast.

The gypsums continue around Barney and Cottonwood creeks with little change in their relationships or thickness. All along the line of hills in this county west of Fairview the effects of solution are very prominent. Caves, or underground channels are numerous and range in size from the very small ones to those 50 feet wide and about the same height and of considerable length. Some are reported to be over a mile long. Bat Cave on Main Creek is one of the best known of the caves of Major County.

The origin of the caves is aparently as follows: The gypsum of this region is selenitic and easily attacked and dissolved by ground water. They are cut by two sets of joints almost at right angles to each other. The crossings of these joints locate points where the ground water can effect its greatest solvent action, and funnel-shaped solution holes are formed. After a hole is formed, the water which flows down through the opening begins to work out through the soft sandy layers which lie immediately below the gypsums. At the canyon wall the water working out from this sand softens it and carries it away thus starting a channel under the gypsum ledge. The head of this channel works rapidly back until it comes under the solution hole or sink. Then if there is a second solution hole back farther from the edge of the hill the process will be repeated and so on, until considerable caves are formed if the conditions are favorable.

If the channel beneath the gypsum should become sufficiently wide and deep, the roof may drop in and after the blocks are dissolved and carried away a narrow steep-sided valley may result. Some of the phenomena of solution are shown in figure 40.

The caves, of course, lie partly in the shales below the gypsums and partly in the gypsums themselves. Where two gypsums are separated by only a few feet of shale, the upper gypsum may form the roof of the cave or channel while the intervening shale, the lower gypsum, and part of the shales below the

Fig. 40.—Sink, cave, and large joint structure in massive gypsum west of Fairview. (Photo by Beede.)

lower gypsum may be removed by solution and erosion to form the cave. An ideal sectioin of such a cave is shown in figurei 41.

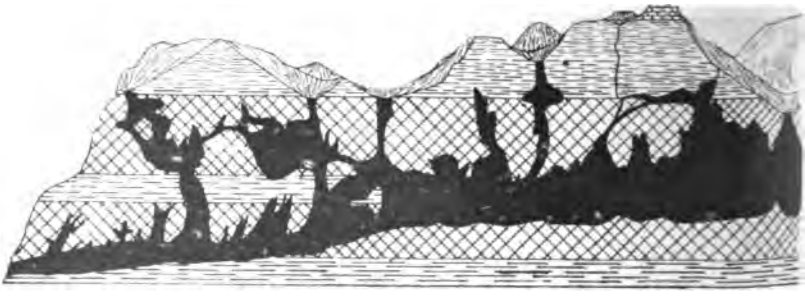


Fig. 41.—Ideal section of gypsum cave. (After Gould, U. S. Geol. Survey.)

Buttes are very common and are often of large size. The best known in this county are those northwest of Fairview called the Glass Mountains. These are a group of outliers or buttes capped by the Ferguson gypsum or by the Medicine Lodge where the Ferguson is absent. One of the most striking of these buttes is shown in figure 42.

The slopes below the gypsum are eroded into a great number of erosion forms, and deeply trenched by running water. The clays below the gypsums are filled with great numbers of

Fig. 42.—Glass Mountains, Major County. (U. S. Geol Survey.)

selenite crystals and thin bands of satin spar. There are also considerable numbers of gypsum concretions. As the slopes are eroded the clay is washed out leaving a layer of selenite and satin spar flakes and gypsum concretions on the surface (fig. 43). These glisten in the sunlight and give rise to the name Glass (cr Glcss) Mountains.

The type of weathering and the presence of selenite and satin spar in the red clays are common along this line of the gypsum hills but the effects are especially striking in the neighborhood of the Glass Mountains. To the south of the Glass Mountains the hills become much less rugged than they are to the northwest. The slopes are more gentle and the gypsums are not well exposed as a general rule. These low hills extend south from Fairview across the line into Blaine County. In this region good exposures are rare and complete sections are not easy to obtain.

On the head waters of Cottonwood Creek the Ferguson gyp-

Fig. 43.—Gypsum concretions covering the slopes of red clay, Glass Mountains. (U. S. Geol. Survey.)

sum shows a thickness of six feet six inches at one locality in sec. 30, T. 21 N., R. 13 W., and about one-half mile to the southeast in sec. 30, over 12 feet of the Shimer is exposed. Two miles farther east, in sec. 33, the following section was made. The contacts at the top of the Medicine Lodge and at the base of the Shimer were not exposed and the thicknessess are therefore approximate.

Section on Gypsum Creek, Sec. 33, T. 21 N., R. 13 W.

		Feet
7.	Shimer gypsum—top removed	15
6.	Honey-combed dolomitic sandstone, at least	2
5.	Covered, probably shale	25
4.	Medicine Lodge gypsum, including at least one foot of anhydrite exposed	6
3.	Greenish dolomitic sandstone	1
2.	Covered, probably shale	13
1.	Ferguson gypsum—base not exposed	6

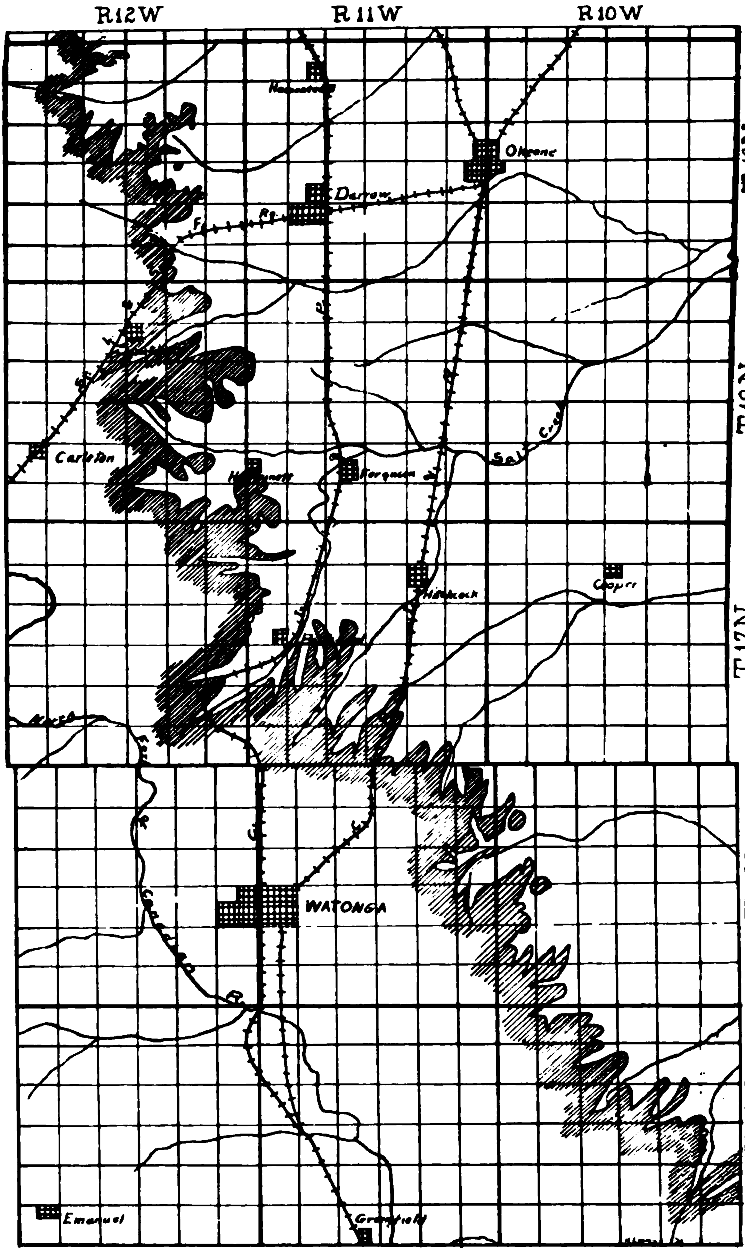
In sec. 6, T. 20 N., R. 12 W., the Ferguson is about six feet thick and the Medicine Lodge is at least 10 feet thick. They are separated by about 17 feet of shale. The Shimer is not shown but the hills are capped by a greeninsh dolomitic sandstone such as occurs under the Shimer. The Shimer probably occurs farther to the southwest. Two miles farther south almost precisely similar conditions are shown. In a cut on the Kansas City, Mexico & Orient Railroad in sec. 29, eight feet of massive white gypsum are shown. It seems to be in the Medicine Lodge but the anhydrite is not shown.

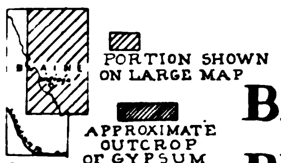
Availability and development of the gypsum.—The gypsum deposits of Major County are at present available only from the line of the Kansas City, Mexico & Orient Railroad south of Fairview. Lines could be run west from this road north of Fairview with comparatively small expense which would render immense quantities of gypsum available, but under present conditions this is not feasible. No use has been made of the gypsum of the county. A mill was projected at Fairview a few years ago but the plans were not carried out. The amount of gypsum present at less than 100 feet deep is estimated by Gould at 12,000,000,000 tons.

BLAINE COUNTY.

Area of outcrop.—The gypsum hills enter Blaine County from the north and extend a little east of south through Tps. 19 and 18 N., R. 12 W. They swing around the head waters of Bitter Creek in T. 17 N., R. 11 W., and then continue southeast across the corners of T. 16 N., R. 11 W., and T. 16 N., R. 10 W., and across T. 15 N., R. 10 W. Throughout most of the county the hills back from the outcrop are covered with sand and the outcrop is usually not over two or three miles wide. The approximate area of outcrop is shown on the accompanying map (fig. 44).

Stratigraphy.—At the Major-Blaine county line the hills are rather inconspicuous and are rounded. To the south they rapidly become more prominent and the canyons are steep sided. Straight west from Darrow the hills show about the same characteristics that they hold throughout the county to the southeast. The exposures in this region are clearer than elsewhere along the line of hills. This is probably due in large





MAP
OF A PORTION OF
BLAINE COUNTY
SHOWING OUTCROP OF
BLAINE GYPSUMS

ıeasure to the nature of the gypsums which have changed from ıe coarsely crystalline selenitic form (which is their principal eature to the northwest) to a fine grained dense form, the typial rock gypsum. This form is apparently much less easily cted upon by water and is not easily dissolved to the extent that he selenitic gypsum is farther to the northwest. Caves and inks while present are not nearly so well developed as in Major County. The steep sides of many of the canyons are also due n part to the presence of the anhydrite member of the Mediine Lodge gypsum, which reaches its maximum development n the vicinity of the head waters of Salt Creek west and southvest of Ferguson. This is more resistant than the gypsum or he shales and makes a vertical face at the top of many of the luffs, from which it breaks off in large blocks when undernined. (see figs. 45 and 46).

Fig. 45.—Anhydrite member of the Medicine Lodge gypsum, salt plain in foreground. (U. S. Geol. Survey.)

The following notes and sections indicate the character of the gypsums as exposed in different localities:

In sec. 8, T. 19 N., R. 12 W., at the head of a canyon in the northeast part of the section the Ferguson gypsum shows a

mile to the southeast in sec. 9, the following section was measured:

Secton in SE. ¼ Sec. 9, T. 19 N., R. 12 W.

		Feet
5.	Medicine Lodge	
	Gypsum—top removed	4
	Anhydrite	3
	Gypsum	8½
4.	Greenish sandy shale and dolomitic sandstones	¾
3.	Red and green shale with selenite and satin spar bands	16
2.	Ferguson gypsum	6½
1.	Greenish dolomitic sandstone	1½

About one mile farther southeast in sec. 16 the Medicine Lodge is at least 15 feet thick and the anhydrite member three feet thick. The contacts are not well exposed and definite measurements could not be made. The Medicine Lodge and the Shimer are separated by 26 feet of green and red shale, filled with selenite bands. The Shimer is 11 feet thick with the top removed and is immediately underlain by one foot or more of greenish dolomitic sandstone.

In the SE. ¼ sec. 23, in the same township the Ferguson shows a thickness of about eight feet. There is a small cave under the outcrop so that the bottom of the ledge is probably removed and the full thickness not shown.

At the quarry of the Oklahoma Gypsum Company at Wilson in the NE. ¼ sec. 26, T. 19 N., R. 12 W., the Ferguson is 8 to 10 fet thick. The anhydrite member of the Medicine Lodge is about three feet thick and has 10 feet of very pure, fine-grained, white gypsum above it. The Independence Gypthickness of six feet, six inches, with the top removed. One sum Company has quarried the Medicine Lodge and Shimer at Southard in sec. 10 T. 18., R. 12 W. The quarry worked in the fall of 1912 is in the Shimer which is here 17 feet thick, massive and fine-grained. The upper 8 to 10 feet is pure white and the lower seven to nine feet somewhat cloudy. The nature of the rock is shown in figure 50. This property was purchased in the fall of 1912 by the United States Gypsum Company.

The following section was taken 200 paces east of the northwest corner of sec. 11, just south of the section line.

Section in NW. ¼ Sec. 11, T. 18 N., R. 12 W., One Mile East of Southard

		Feet
11.	Anhydrite, at top of hill .... about	4
10.	Gypsum, white, massive	5
9.	Greenish grey sandstone	½
8.	Red shale with green bands	9
7.	Red and green shale with satin spar and green selenite bands	11
6.	Ferguson gypsum, mottled	7
5.	Greenish dolomitic sandstone	½
4.	Red and green shale	8
3.	Green selenite in clay, satin spar	1½
2.	Red shale with thin bands of satin spar	7
1.	Red and green shale with some selinite	30

In this section Nos. 10 and 11 represent the Medicine Lodge. The upper gypsum has been removed by erosion. The Shimer shows about 15 farther back on the hill. The appearance of the weathered surface of the anhydrite, No. 11, is shown in figure six, in chapter one.

Around the head waters of Salt Creek, west of Ferguson, the gypsum hills are higher and more rugged than anywhere else along the outcrop of the Blaine formation. As previously mentioned this is probably due to the ledge of anhydrite which reaches its maximum development here, where it is four to five feet thick. The appearance of the ledge and the manner in which it produces the steep slopes are shown in figure 46.

The following section by Gould was measured at the bluff at the old plaster mill west of Ferguson:

Section Taken on the South Canyon of Salt Creek, at the Rubey-Stucco Plaster Company's Mill

		Feet
7.	Massive, white gypsum, the Shimer	15
6.	Soft, gray dolomitic sandstone	1
5.	Red gypsiferous clay	27

Fig. 46.—Anhydrite blocks from Medicine Lodge gypsum, 4 miles west of Ferguson.

4.	Massive white gypsum, the Medicine Lodge (Contains 3/4 feet anhydrite)	17
3.	Red gypsiferous clay, with green bands of selenite	25
2.	Pinkish, mottled gypsum, the Ferguson	4
1.	Red gypsiferous clay, with thin green and white selenite bands and layers....................	86

The clay underlying the Ferguson is locally very salt and, in Henquenet's Canyon, near the head of Salt Creek gives rise to many salt springs. These are described in the succeeding chapter of this report.

To the southeast the gypsums show little change in their character and relations for a few miles. In the E. ½ sec. 18, T. 17 N., R. 11 W., across Bitter Creek from the Roman Nose Gypsum Company's mill the following section was measured:

Section Near Bickford i nSE. ¼ Sec. 18, T. 17 N., R. 11 W.

		Feet
6.	Shimer gypsum, top eroded	14
5.	Red and green shale	32
4.	Medicine Lodge gypsums	
	Gypsum	9
	Anhydrite	2
	Gypsum	6
3.	Red and green shales	32
	(a 12-14 inch layer of gypsum near the middle)	
2.	Ferguson gypsum	5 to 6
1.	Red shales	70

The contacts at the bottom of the gypsum ledges are not clearly enough exposed to tell whether or not thin layers of dolomitic sandstone usually present immediately under the gypsums occur in this section. The general character of the outcrops in this region is shown in figure 47. This picture was taken north of the Roman Nose Gypsum Company's mill at

Fig. 47.—Hill near Bickford, showing the three gypsum beds.

Bickford. The Ferguson shows as a bench about one-third of the way up the hill, the Medicine Lodge caps the main hill, while the Shimer caps the outlier at the right of the picture. The white blocks at the foot of the hill and on the slopes are mostly anhydrite from the middle of the Medicine Lodge. The ledge of anhydrite shows about the center of the figure.

Four miles to the southeast of the section just described are the quarries of the Monarch Plaster Company and the American Cement Plaster Company. They are situated in secs. 27 and 34, T. 17 N., R. 11 W. The following section was made by Gould along the Chicago, Rock Island & Pacific Railway at this locality.

Section Along the Chicago, Rock Island & Pacific Railway, Four Miles South of Hitchcock.

		Feet
8.	Massive, white gypsum, the Shimer	8
7.	Gray, dolomitic sandstone	1
6.	Red clay	45
5.	White, massive gypsum, the Medicine Lodge	12
4.	Gray dolomitic sandstone	2
3.	Red clay shales with greenish bands	17
2.	Massive white gypsums, the Ferguson	3
1.	Red clay shales with bands of gypsum	90

The thin gypsum observed between the Ferguson and Medicine Lodge in the section at Bickford is not recorded in this section by Gould. It is exposed, however, in the railroad cut in sec. 27, where it has a thickness of about one foot. Between the Bickford section and the one at the quarries south of Hitchcock the Shimer thins perceptibly and the anhydrite in the Medicine Lodge becomes lenticular and is practically absent in the Monarch and American quarries which utilize the whole thickness of the Medicine Lodge. The satin spar veins in the shales between the gypsums are very abundant in this region and are thicker than usual. (See fig. 48).

Southeast from the Monarch and American quarries, the Shimer continues to become thinner, the Medicine Lodge thins to about seven feet and the Ferguson to three feet while the fourth gypsum, between the Ferguson and the Medicine Lodge, gradually thickens to three feet. This layer is quite selenitic

Fig. 48.—Satin spar veins in clay, north of Watonga. (U. S. Geol. Survy.)

while the others are fine-grained. In sec. 19, T. 16 N., R. 10 W., the following section was measured:

Section in SW. 1/4 Sec. 19, T. 16 N., R. 10 W.

		Feet
8.	Shimer gypsum	6
7.	Dolomitic	½
6.	Red and green shales with thin dolomitic layers	42
5.	Medicine Lodge gypsum	7
4.	Covered, probably shale	20
3.	Gypsum, selenitic	2
2.	Covered, probably shale	25
1.	Ferguson gypsum	3

The contacts in this section are not sharply exposed and the thicknesses are approximations. The dolomitic layer beneath the Shimer is very fossiliferous, containing large members of pelecypods. The character of the steeper hills in this

region is shown in the accompanying view of Cedar Hills (fig. 49).

Fig. 49.—Cedar Hill, east of Watonga, showing Ferguson gypsum on the slope and Medicine Lodge gypsum as a cap. (U. S. Geol. Survey.)

Farther to the southeast the Shimer disappears, the dolomitic layer beneath it continues as a thickened, blue to white magnesian limestone, which is locally fossiliferous. In T. 15 N., R. 10 W., the hills grow less and less distinct until at the Blaine-Kingfisher county line they die out to reappear across the line in Kingfisher county.

The following section was measured on a butte two miles west of Altona and one mile west of the line between Blaine and Kingfisher counties.

Section in NE. 1/4 Sec. 14, T. 15 N., R. 10 W., Two Miles West of Altona

		Feet
7.	Medicine Lodge gypsum, top removed by erosion	3
6.	White dolomitic sandstone	2
5.	Red and green shales	16

4.	Gypsum, anhydrite, with satin spar beneath	3
3.	Red and green shale	18
2.	Ferguson gypsum, selenitic	3
1.	Red and green shale	21

Availibility and develcpment of the gypsums.—Blaine County is well supplied with railroads and the gypsums are more accessible than those of any other county along the first line of hills. Three railroads cross the outcrop in the northern part of the county and a fourth is sufficiently near the outcrop to render the gypsums available.

The Kansas City, Mexico & Orient Railroad crosses the outcrop south of Fairview in Major county and remains near the top of the hills for some distance into Blaine County. Spurs two or three miles in length built from this road in the vicinity of Longdale would open up immense deposits. At present there is no development along this road although a mill has been proposed at Longdale.

The Kansas City and Vernon branch of the St. Louis & San Francisco Railroad approaches the outcrop at Wilson east of the center of sec. 26, T. 19. N., R. 12 W., turns south along the foot of a hill which is capped by the Medicine Lodge gypsum. The scarp continues to the southwest on top of the gypsums. In sec. 10, T. 8 N., R. 12 W., a branch of Squaw Creek carries the outcrop back near the railroad and makes a large amount of rock easily available. Two mills with their quarries and the quarry of the third mill, are located on this road.

The new mill and quarry of the Oklahoma Gypsum Company is located at Wilson east of the center of sec. 26, T. 19 N., R. 12 W. The mill is on a short spur from the railroad, at the foot of a hill which is caped by the Medicine Lodge gypsum. The quarry is opened in the Ferguson which is about six feet thick and of a very good quality. From the quarry the rock is hauled to the mill in steel dump cars on a tramway. A large quantity of rock can be obtained from the Ferguson ledge before the stripping becomes prohibitive. It is planned to open a second quarry in the Medicine Lodge above the anhydrite. A thickness of 10 feet of exceptionally pure white gypsum can be obtained with very little stripping.

The present quarry of the Southwest Cement Plaster Com-

pany (leased to the Oriental Plaster Company), whose mill is at Okeene, is on the end of a nose in the south part of sec. 26. The material is crushed in a crushing plant located beside the railroad, run into cars on a switch, and hauled to the mill. The quarry opening is small. The old quarry of this company is near the north line of sec. 2, T. 18 N., R. 12 W. The Medicine Lodge gypsum above the anhydrite was quarried. The opening is about 375 by 125 feet in dimensions. The crushing plant was formerly located at this point.

The mill and quarry of the Independence Gypsum Company at Southard was purchased in the fall of 1912 by the United States Gypsum Company. The quarries are located in the NW. 1/4 sec. 10, T. 18 N., R. 12 W. Both the Medicine Lodge and the Shimer have been quarried; about five acres of the Shimer and one acre of the Medicine Lodge have been removed since work began in 1905. In the fall of 1912 a quarry in the Shimer was being worked. The ledge here averages 17 feet in thickness and the greater part is pure white.

The lower five or six feet is somewhat cloudy but burns white. The stripping is usually less than two feet, but many of the joints are opened by solution and considerable work is resuired to remove the clay from the joints. A small portion of the quarry is shown in figure 50. The rock is hauled to the mill, a distance of over one-fourth mile, in wagons and unloaded by hand. Twelve men were working in the quarries and on the wagons at the time the quarry was visited, but as high as 25 men have been employed when the mill was running to capacity.

The Geary-Alva branch of the Chicago, Rock Island & Pacific Railway comes near the gypsum hills southeast of Ferguson and follows closely along the foot of the hills through the canyon of Bitter Creek (Roman Nose Canyon) from the lines between secs. 7 and 18 for about three miles to the southwest where it goes up over the gypsums near the head of the canyon. Two mills are located along this road.

The old mill of the Rubey Stucco-Plaster Company is situated about four miles west of the railroad near Ferguson in the South Canyon, near the head of Salt Creek. The quarry is at the top of a hill about 250 feet above the level of the bottom of the canyon. The Medicine Lodge gypsum was quarried. The

Fig. 50.—A portion of the quarry of the United States Gypsum Company in the Shimer gypsum at Southard.

rock was lowered to the mill in cars operated by a gravity system on a double track. Owing to its being located so far from the railroad this mill has not been successful and has not been operated for some years. The tracks from the quarry to the mill have been destroyed. There is no prospect of the mill being operated in the near future.

The Roman Nose Gypsum Company owns the SE. 1/4 and

the E. ½ NW. ¼ sec. 18 and the E. ½ SW. ¼ sec. 7, T. 17 N., R. 11 W. The railroad lies parallel to the hills on the west side of the track less than one-eighth mile from the hills on the east. The quarries are in the Medicine Lodge gypsum, above the anhydrite layer. A thickness of five to six feet of good rock can be obtained near the outcrop and eight to nine feet is accessible farther back in the hill. However, the thickness of stripping also increases very rapidly so the quarrying is not carried far from the outcrop until the stripping becomes heavy, and a third quarry has been opened. It is planned to strip the anhydrite from the old quarries and to utilize the gypsum below it, which is about six feet thick and of good quality. The rock is hauled from the quarry to the mill in wagons and unloaded by hand. The location of the quarries and mill is shown in figure 51 and the mill and its surroundings in figure 52.

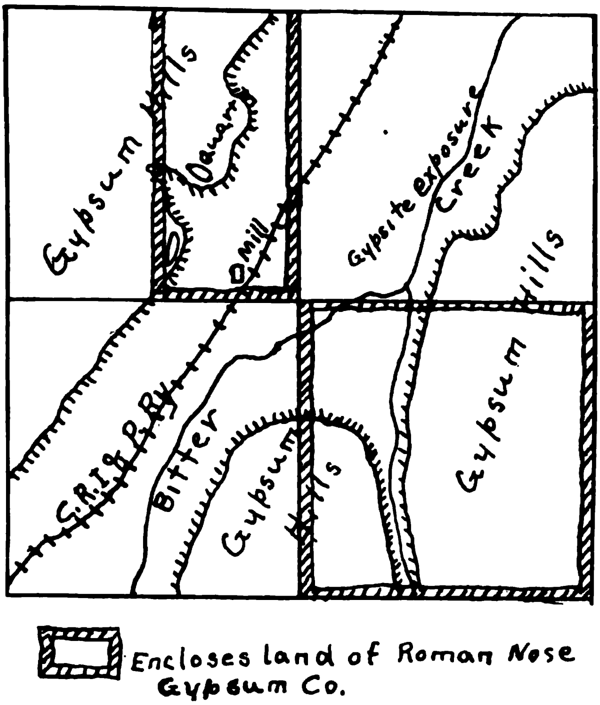


Fig. 51.—Map of sec. 18, T. 17 N., R. 11 W., showing buildings of Roman Nose Company.

Fig. 52.—Mill of the Roman Nose Gypsum Company at Bickford.

The Enid, Lawton, and Waurika branch of the Chicago, Rock Island & Pacific Railway crosses the gypsum hills about four miles south of Hitchcock. It makes the gypsum deposits of sec. 27 and 34, T. 17 N., R. 16 W., easily accessible. Two quarries, those of the Monarch Plaster Company (leased to the Oriental Plaster Company) and of the American Cement Plaster Company whose mills are at Watonga, are located in these sections. The location of the quarries, gypsite beds and of the hills in these sections and in sec. 35 are shown in figure 53. The small map (fig. 54) shows the location of the holdings of the Roman Nose Gypsum Company, the Monarch Plaster Company, and the American Cement Plaster Company in T. 17 N., R. 11 W.

The quarry of the Monarch Plaster Company is in the NE. 1/4 SE. 1/4 sec 27. It is opened along the railroad cut and a short spur is laid into the quarry. The entire Medicine Lodge bed is quarried giving a thickness of 12 to 15 feet of gypsum. The stripping is very thin as far back as the face has been worked but increases very rapidly back into the hill. A large quantity of rock can be secured before the stripping becomes very heavy. The conditions of the quarry are shown in figure 55.

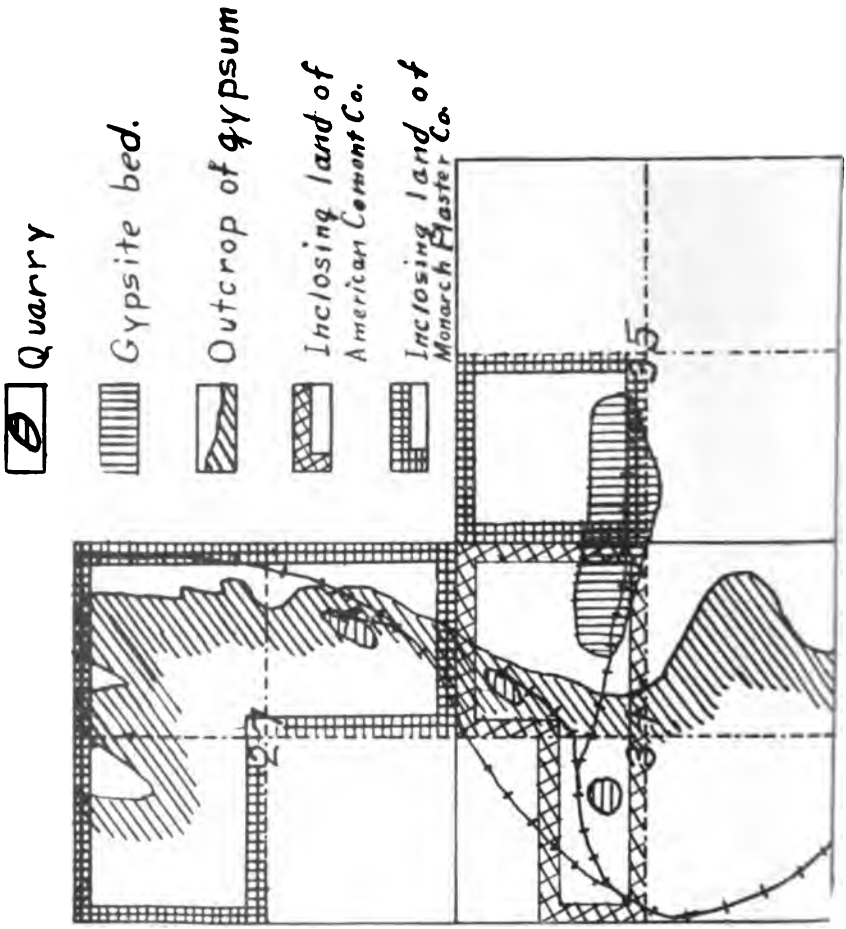


Fig. 53.—Map of sections 27, 34, and 35, T. 17 N., R. 11 W., showing the holdings of the American Cement Plaster Company and the Monarch Plaster Company.

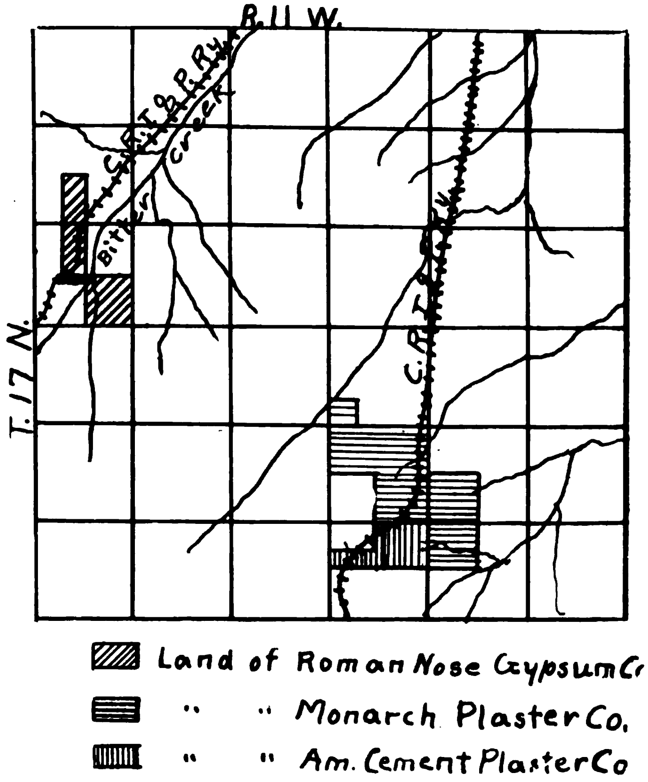


Fig. 54.—Sketch map of T. 17 N., R. 11 W., showing holdings of gypsum companies.

Fig. 55.—Portion of quarry of Monarch Plaster Company.

The quarry of the American Cement Plaster Company is the NE. 1/4 NE. 1/4 sec. 34. T. 17 N., R. 11 W. The quarry worked at present was opened in the summer of 1912, and the opening is still small, less than one-eighth acre having been removed. The nature of the rock and quarrying conditions are identical with those of the Monarch quarry which is only 40 rods distant. The rock is hauled from the quarry face in end dump cars on a track to the crushing plant. The plant has a jaw crusher and cracker of a capacity of 10 tons per hour. The power is furnished by a 40 horse power, Fairbanks-Morse internal combustion engine which uses solar oil as fuel. The gravel from the cracker is elevated and runs directly into cars on the spur track from the railroad. Twelve to fourteen men are employed at the quarry and crusher, at 20 cents per hour. A portion of the quarry is shown in figure 56.

Gypsite beds.—The gypsite beds of Blaine County seem to be more extensive than those of any other county along the first line of hills, but this may be on account of their being better developed. From the nature of the occurrence of gypsite beds it is evident that beds covering considerable areas may be present without being exposed. or may be exposed in such small

Fig. 56.—Portion of the American Cement Plaster Company's quarry in the Madicine Lodge gypsum northeast of Watonga.

patches as to escape notice unless detailed search is made for them, and little search has been made in counties having no mills.

Three small gypsite beds lie in the draws in E. ½ sec. 27, T. 19 N., R. 12 W., about one mile west of the Oklahoma Gypsum Company's mill at Wilson. One bed is about 100 feet by 750 feet and shows a maximum thickness of seven feet of gypsite. At a short distance from this is a second bed about 350 feet square. The full thickness is not shown but the bed is over two feet thick. A similar bed lies to the east. It probably extends down the draw 300 to 400 feet.

The gypsite beds of the Southwest Plaster Company (mill at Okeene) lies in the south-central part of sec. 35., T. 19 N., R. 12 W., and in the adjoining part of sec. 2 in the township to the south. The opening in sec. 2 is about 125 by 375 feet. In thickness the gypsite ranges from about two feet at the foot of the hill to five to eight feet at the creek. The stripping is two feet thick, of the soil near the hill and five feet near

the creek. This bed extends east on to the land of the United States Gypsum Company. The quality of the gypsite is better near the creek. The material is hauled to the railroad in wagons and dumped into the railroad cars through a trap. The opening in sec. 35 is about 125 feet square. In thickness and quality the bed is similar to that to the south. The gypsite is hauled to the railroad in wagons whose beds are elevated and dumped into the cars by means of a derrick.

Large deposits of gypsite lie along Bitter Creek at and near Bickford. Exposures are seen at intervals for a distance of about two miles along the creek and in some of its small tributaries. The bed used by the Roman Nose Gypsum Company lies principally on the east side of Bitter Creek in the NW. 1/4 sec. 19 and the SW. 1/4 sec. 18, T. 17 N., R. 11 W., less than one mile from the mill. In thickness the deposit varies from one foot at the foot of the hill to five feet along the creek and it is covered by soil a few inches to two feet thick. The bed is approximately five-eighths mile long and averages about 75 feet wide. The gypsite is removed by drag scoops and dumped through a trap into wagons. Only about one-tenth of the estimated quantity of the deposit has been used in the five years that the mill has been running.

The mills at Watonga obtain their gypsite from a large bed lying in the SE. 1/4 NE. 1/4 sec. 34 and the NW. 1/4 sec. 35, T. 17 N., R. 11 W. The entire bed covers about 80 acres and the maximum thickness is about eight feet. The material is worked with drag scoops and dumped through a trap into railroad cars on a spur track from the Chicago, Rock Island & Pacific Railway. Judging from a general view of the workings less than one-half of the available material has been removed.

KINGFISHER COUNTY.

Area of outcrop.—The gypsum hills cross the extreme southeastern corner of Kingfisher County. The escarpment lies in secs. 30, 31, 32, and 33, T. 15 N., R. 9 W. The approximate area of outcrop is shown in figure 57.

Stratigraphy.—The gypsum hills die out just about the line between Blaine and Kingfisher counties but reappear in Kingfisher and continue into Canadian County. It is not known

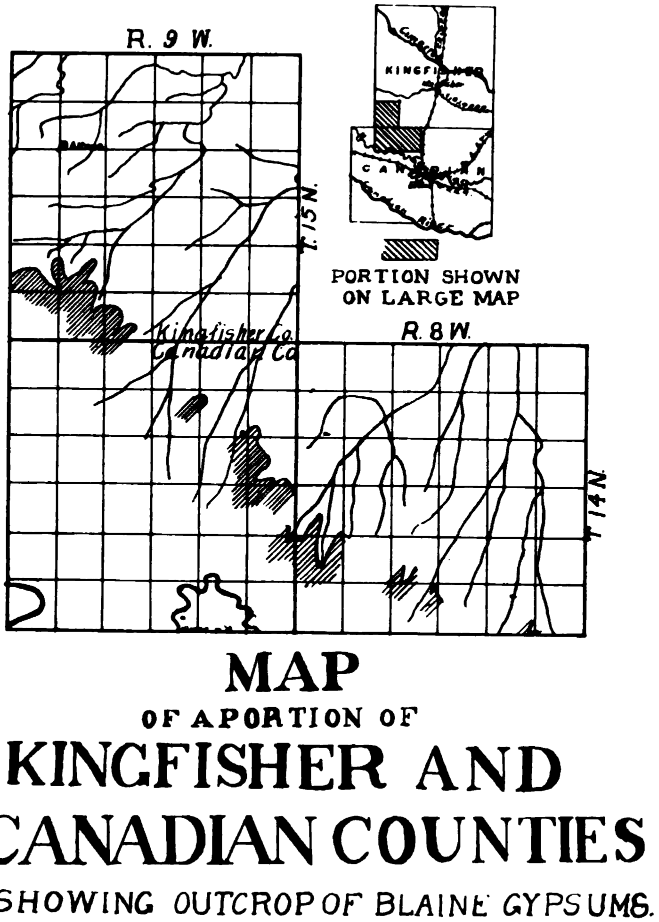


Fig. 57.—Map of a portion of Kingfisher and Canadian counties showing outcrop of Blaine gypsums.

whether the gypsums are absent along the Blaine-Kingfisher county line or whether they are merely covered. In Kingfisher County the section is apparently the same as in the adjoining part of Blaine County. Good exposures are rare. The thickness and relations of the gypsums are shown in the following sections:

Section in NW. 1/4 Sec. 29, T. 15 N., R. 9 W.

		Feet
6.	Medicine Lodge gypsum, pink, top eroded	4
5.	Sandy, white dolomite	2
4.	Covered, probably shale	16
3.	Gypsum, with satin spar immediately underneath	2
2.	Covered, probably shale	16
1.	Ferguson gypsum	5

Just north of the Kingfisher-Canadian county line the stratification becomes very erratic and the ledges cannot be traced.

Availability and development of the gypsums.—The gypsums of Kingfisher County are not near enough to a railroad to be considered available at present. No development has been undertaken. Gould estimates the amount of gypsum at 50,000,000 tons.

CANADIAN COUNTY.

Area of outcrop.—The gypsum hills extend into Canadian County from Kingfisher and reach almost to Darlington on the Chicago, Rock Island & Pacific Railway. The hills are not conspicuous and the slopes are gentle.

Stratigraphy.—Just before they cross the south line of Kingfisher County the outcrop of the gypsums becomes discontinuous and the individual ledges cannot be followed. In the north part of T. 14 N., R. 9 W., three gypsums are present which may or may not be the reappearance of the Ferguson, Medicine Lodge, and the unnamed gypsum between them. The upper and lower gypsums are each about three feet thick and the middle one i sabout one foot. All three are usually white but the top parts are sometimes pink and selenitic. The thin middle ledge is occasionally very impure, sometimes clayey and often anhydritic. In T. 14 N., R. 8 W., gypsum occurs in lenticular beds. One of these beds is quarried at the Okarhe mill of the United States Gypsum Company in sec. 34. Southwest of this point the gypsums finally disappear.

Availability and development of the gypsums.—The gypsums of Canadian County approach the Chicago, Rock Island &

Pacific Railway north of El Reno. The only development is the quarry mentioned in the preceding paragraph. This property was closed in 1912 and will probably not be reopened.

SECOND LINE OF GYPSUM HILLS.

GENERAL STATEMENT.

The second line of gypsum hills is formed by the eastern portion of the outcrop of the Greer formation. As has been observed, this formation consists of red shales and red sandstones with subordinate amounts of gypsum and dolomite or magnesian limestone. The stratification in the area under consideration is very erratic and the gypsum ledges are not continuous over large areas as is the case in the first line of gypsum hills. Ledges of gypsum several feet in thickness may pinch out or grade laterally into sandstone in the distance of a few rods. As a consequence of this irregularity of stratification the hills in this region differ strikingly from those of the first line. Instead of a single bold escarpment with outlying buttes, the hills are a series of rounded knolls usually covered by grass, or a series of long rounded ridges. Good exposures of any considerable thickness of rock are comparatively rare. The eastern margin of the hills lies from 25 to 50 miles west of the main line of hills. The width of the gypsum outcrops varies from about five to about 30 miles. The areas occupies parts of the following counties: Dewey, Ellis, Roger Mills, Custer, Washita, Kiowa, Caddo, Comanche, and Grady. These counties will be considered in turn commencing at the north. The outcrop of the Greer formation is shown on the general geologic map (fig. 30).

DEWEY COUNTY.

Although the Greer formation outcrops over a considerable portion of Dewey County, the gypsums are thin and relatively unimportant. The high hills north of the Canadian River north and northwest of Taloga are capped by a ledge of rock gypsum four or five feet thick. The gypsum appears to be of good quality but so much of the ledge has been removed by erosion that the areas remaining are comparatively small. No location was observed which seemed suitable for a mill site even if there were transportation facilities at hand. The same ledge

continues to the southwest up the river as far as Raymond, and what is probably the same ledge appears at Camargo on the Wichita Falls & Northwestern Railway. Large quantities of gypsum were removed from the railroad cut about one mile north of the town, where the ledge shows a thickness of about four feet. In this locality there seems to be more than one ledge, but the stratification is very erratic, or the gypsums are locally removed by solution and can not be traced along the hillsides for any considerable distance. In at least one case, a bed of gypsums seems to be inclined, that is, to cut across the lines of stratification of the shales and sandstones. No explanation for this phenomenon is offered. The grading of sandstone into gypsum is also well shown here. In tracing a ledge of ordinary redbeds sandstone, a few small white specks or patches of gypsum will be found widely separated in the sand. These increase laterally in number and size very rapidly until, sometimes in the distance of a few rods, the sandstone is entirely replaced by gypsum. The gypsum ledge may continue for a considerable distance, but in many cases grades back into sandstone in a distance of a fraction of a mile. Although the quantity of gypsum at Camargo is large the extreme irregularity of its occurrence, and the amount of stripping which would be necessary to secure a sufficient supply for a mill for any length of time, render its development improbable, at least in the present state of the plaster industry. Six miles northeast of Leedy gypsum ledges show on the hillsides along Stinking Creek and some of its tributaries. In one locality there are apparently four beds, ranging from two to four feet in thickness. These beds can be traced only a short distance and all have considerable cover except at the outcrop. Gypsums show in the bottoms of the canyons and are reported from wells in the vicinity of Putnam and in the southern part of the county but no commercial deposits were observed. The lack of transportation makes deposits in this part of the county unavailable even if they were suitable for development in other respcts.

Gould estimates the amount of gypsum available in Dewey County at about 1,000,000,000 tons. Of this amount, however, it is doubtful if any is practically available at present. The only location where it seems at all possible that a mill could be successfully operated is at Camargo, and this locality should be carefully prospected before any definite steps towards de-

velopment are taken. No deposits of gypsite are known in the county although it is entirely possible that some beds may be present.

ELLIS AND ROGER MILLS COUNTIES.

The gypsum beds extend up the South Canadian River westward into Ellis and Roger Mills counties, in the area occupied by what was formerly Day County. In Ellis County on the north side of the river, gypsum is exposed along Turkey Creek in the vicinity of Stone. On the south side of the river in Roger Mills County, the gypsum appears near Shirley and extends for some distance up the river. The amount of the available gypsum in the two counties will probably not exceed 500,000,000 tons.

CUSTER COUNTY.

The greater part of Custer County is underlain by the Greer formation and gypsum is of common occurrence except in the extreme northeastern part and in the western row of townships. The gypsum beds increase in thickness and in regularity from northwest to southwest and attain their maximum in this county near Weatherford in the southeastern corner.

In the northwestern part of the county the beds are well exposed in the tributaries of Barnitz Creek in the vicinity of Osceola. Thicknesses of 10 feet of gypsum were observed but all the beds in the immediate vicinity of Osceola outcrop low down on the slopes or in the bottom of ravines so that they can scarcely be considered available even if there were transportation facilities. Farther to the east two ledges, five feet or less in thickness show about three miles north of Independence. These ledges are apparently not continuous over sufficient area to make them of any importance. Three beds show in the draw and ravines about two miles north of Custer City but they are not commercially important. Northwest of Clinton, along the line of the Clinton, Oklahoma & Western Railway, gypsum shows near Stafford. The amount easily available, however, is too small to render the deposit of commercial value. Considerable thicknesses of gypsum show in the vicinity north of Butler but the stratification is so erratic that it is difficult to estimate the

amount present. A somewhat hurried examination failed to show any deposits which seemed capable of development.

In a ravine one mile north of Butler a phenomeon was observed which may account in some measure for the seeming irregularity of the stratification of the gypsum in this vicinity. A bed of gypsum lies on the hills back from the ravine. The water which runs over this gypsum and down the small draws into the ravine carries considerable gypsum in solution. Where the supply of water is not sufficient to erode the sides of the ravine rapidly but must run down the sides slowly, there is sufficient evaporation to form an encrustation on the side or wall of the ravine, which may reach a thickness as great as six inches. This encrustation gives the appearance in every respect of a ledge of gypsum of a thickness equal to the height of the wall of the ravine up to the level at which the water leaves the small draws. It seems possible that this secondary deposition caused by gypsiferous water evaporating on fairly steep slopes may account in a small degree for the appearance of thick ledges of gypsum which seem to play out in very short distances. By far the greater portion of these appearances, however, must be due to other causes, such as lateral gradation into sandstone or shale, solution of part of the ledges, lenticular beds, and slip which covers part of the ledge.

The commercially important deposits of gypsum in Custer County lie in the extreme southeastern corner in T. 3 N., R. 15 W., and T. 12 N., Rs. 14 and 15 W., in the vicinity of Weatherford. The hills which extend northwest from Weatherford to the west of Deer Creek and its tributaries, contain ledges of gypsum up to 50 feet in thickness, and equally important beds are found due south and to the southwest of Weatherford. The deposits are available from the Chicago, Rock Island & Pacific Railway. No beds of commercial importance were found immediately on the railway but spurs of one mile or less in length would open up immense beds of gypsum. The gypsum varies in quality, but the prevailing type is a fine-grained, selenitic rock of white, pink, or red color. The following analyses of gypsum near Weatherford are given by Gould: [82]

[82]Gould, Chas. N., Water-supply paper U. S. Geol. Survey No. 148, 1905, p. 63.

Analyses of Gypsum From Near Weatherford.

A. Gypsum from cave five imiles northwest of Weatherford.

B. Gypsum from ledge four miles west of Weatherford.

C. Gypsum from ledge five miles west of Weatherford.

	A	B	C
Calcium sulphate	75.57	77.38	27.25
Calcium carbonate	1.11		46.73
Magnesium sulphate		.83	
Magnesium carbonate	.40		1.42
Water	20.22	20.78	17.36
Oxides or iron and aluminum	.45	.67	8.30
Silica and insoluble residue	1.66	.41	1.22
	99.41	100.07	102.28

The effects of solution on the thick gypsum ledges are very noticeable and caves and sinkholes abound. The entrance to the cave five miles northwest of Weatherford from which sample "A" in the above list was taken is shown in figure 58.

Gypsite beds.—Judging from the conditions in Custer County, there should be considerable deposits of gypsite present. No detailed prospecting has been carried on, however, and at present only one bed of importance is known. This lies in sec. 1, T. 12 N., R. 16 W., and in the adjoining section on the north. The Chicago, Rock Island & Pacific Railway passes through the deposit about one mile east of the station at Indianapolis. The gypsite bed covers between 60 and 70 acres and reaches 18 feet in thickness. The greater part of the material is a fine, light gray gypsite with little sand. The lower portion is a very light reddish brown in color, and somewhat more sandy. The cover consists of from one to eight feet of soil. The extent of this deposit, the character of the material, and its location with respect to the railroad, make it of undoubted commercial importance and its development is probably a matter of a short time.

Summary.—Gypsum occurs over the greater part of Custer County but is of commercial importance only in the extreme southeastern portion. Here, in the vicinity of Weather-

Fig. 58.—Entrance to gypsum cave 5 miles northwest of Weatherford.

ord ledges up to sixty feet thick occur in a short distance of he railroad. The gypsite bed near Indianapolis is apparently f considerable importance. There is no development of the gypsum of the county at present. The amount of gypsum in he county is estimated by Gould, at 6,000,000,000 tons.

WASHITA COUNTY.[83]

The area in Washita County underlain by the Greer formation lies principally in the eastern half of the county. In the southern part the area splits, one part extending west, north of the southern line of the county, and the other to the southeast across the southwestern part of Caddo County.

The gypsum of the eastern part of the county occurs at two general horizons, a lower, which outcrops along Washita River from the Washita-Custer county line south, well into T. 18 N., where it swings away from the river to the east and west and seems to die out; and an upper horizon which caps the high hills along the river. The two groups are usually separated by 100 to 150 feet of shales and sandstones. Both horizons or groups are composed of very thick massive gypsum usually of a pink color. Neither group appears to consist of a continuous ledge although only one is usually present at a given location. From the appearance of the outcrop and the varying thickness of the intervening shales and sandstones, it is thought that each group consists of a series of lenticular beds lying at the same general level.

As has been said above the upper group occurs only on the top of the hills. It is probably present in many places where exposures were not found since many fields are reported as being underlain by gypsum at a depth of a few feet where there are no natural exposures. This gypsum is well developed in T. 11 N., Rs. 15 and 16 W., and probably extends to the south and connects with the large area along the east county line in T. 9 N., R. 14 W. In only a very few cases were exposures of this gypsum observed to cross the line into Caddo County and these exposures persist for only one-fourth to one-

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[83]The description of the deposits in Washita County is taken principally from the note book of Jerry B. Newby, who did practically all the field work in this county.

half mile. The gypsum for the most part is fine-grained, massive, and pink. Locally there is considerable white gypsum but uniformly very little selenite. It is reported that a well in sec. 26, T. 11 N., R. 15 W., passed through 70 feet of this gypsum. The exposures on the hill tops in the vicinity show apparent thicknesses that make this well log seem entirely credible. The horizon of this gypsum is probably the same as that of the gypsum at Weatherford. The cover of this gypsum is usually thin or wanting.

The lower horizon of gypsum is much better exposed than the upper. Outcrops are found along the Washita River from the north line of the county extending to within five miles of Mountain View on the south line. In the northern part of the county the ledge is down near the level of the flood plain of the stream. To the south the gypsums are found higher and higher above the stream until they are well up from it and swing away from the river valley. Probably the best exposures are near Cloud Chief, Cowden, on the Washita River due east of Cordell, and on the state road on the south side of sec. 34, T. 10 N., R. 15 W. In sec. 35, of the same township and range, there is a bluff of gypsum which exposes a maximum thickness of about 45 feet. The true thickness is probably in excess of 50 feet since both the top and bottom of the bed are covered. The gypsum is pink on fresh surfaces but weathers locally to a dark red. In one place a lentil of gypsiferous sandstone one to three feet thick, with two large veins of satin spar, is exposed near the middle of the ledge. The length of this bluff is about one-third mile. A smaller bluff showing 20 feet of gypsum and having a length of about 100 yards is four miles due north of the one just described. The cover of the gypsum in both of these bluffs increases very rapidly back into the hill.

In sec. 3, T. 9 N., R. 15 W., along a tributary of the Washita there is a gypsum bluff 50 feet in height. The lower part of this ledge, consisting of a thickness of 10 feet, is a hard pink rock, probably anhydritic. The remaining part consists of a massive gypsum ranging in color from pink to white. Near Cowden in secs. 18 and 19, T. 9 N., R. 15 W., 10 to 20 feet of pink and white gypsum are exposed. There are two ledges, the lower is about eight feet thick and the upper at least 12 feet with the top removed. The two are separated by eight to 10

feet of shale. The under part of the lower ledge is very hard and probably anhydritic.

From the preceding notes, it is seen that wherever the lower part of this thick gypsum is exposed, there is at the base a band, eight to 10 feet in thickness, of harder—probably anhydritic—gypsum, sometimes separated from the main portion of the ledge by shale. The heavy body of gypsum is a more or less continuous ledge, and the outcrop can be followed for several miles in some places. In T. 8 N.. R. 15 W., the outcrop swings to the west and disappears in about 10 miles. Only small exposures of thin gypsum are reported to the east.

Besides the two main bodies of gypsum mentioned there are some other beds in the eastern part of the county. The exposures are few and seldom show a thickness of over two or three feet. In the northwestern part of the county the beds are apparently very thin and not widely distributed. Only two outcrops were noted and the thickness exposed in these was not over one foot.

In the western extension of the belt of the Greer formation along the southern line of the county three gypsum ledges appear. In sec. 28, T. 8 N., R. 20 W., the lowest ledge is 16 feet thick. The gypsum is very hard and seems to be largely anhydritic. In these localities the rock breaks from the bed in blocks formed by two sets of joint planes meeting at about right angles and spaced a few feet apart. This gives smooth vertical faces, which are banded with alternating, waving light and dark stripes. The middle ledge is of the same thickness but is composed entirely of selenitic gypsum. No good exposures of the upper ledge were observed, but it appeared thicker than either of the other two. The upper ledges are entirely white. A thickness of 50 feet of gypsum is reported from a well in the section.

Gypsite beds.—So far as has been observed the conditions in Washita County are favorable to the occurrence of large gypsite deposits but at present only a few small beds are known, none of them cover more than three acres. They cannot be considered commercially valuable and there is no necessity for detailed description.

General summary.—Washita County contains immense deposits of rock gypsum, along Washita River in the eastern

half of the county. The railroad nearest to the greater part of the deposits is the Arkansas City and Vernon branch of the St. Louis & San Francisco Railroad which lies six to 10 miles west of the region where the gypsums could be well worked. This distance is practically prohibitive under the present conditions of the plaster industry. Small gypsite beds are known but they are not of commercial importance at present. Gould estimates the amount of gypsum in the county at a depth of less than 100 feet as 20,000,000,000 tons, a greater amount than that of any other county in the state.

CADDO COUNTY.

Very little attention was given to the Caddo County deposits in preparation for this report since they have already been rather fully described by Gould.[54] His description is given in full.

"In Caddo County there are deposits of gypsum both north and south of the Washita River. In the region of the Keechi hills in the southeast corner of the county, on the line of the Frisco Railroad between Chickasha and Lawton there are deposits of considerable magnitude. These deposits extend from the Comanche line north to the Keechi hills and beyond. East and west they occupy an extent of some twelve or fifteen miles. In all, the outcrops of gypsum in this locality occupy about two townships. The ledges are not continuous but the gypsum appears as rounded knobs on the prairie or as irregular ledges along the sides of the stream. The gypsum consists of a mixture of hard rock and dirt gypsum. In places the dirt gypsum or gypsite, predominates while in other localities all the material is a rather hard rock. Plenty of localities may be found where a mill could be located for which an abundant supply of dirt gypsums could be optained. The gypsum in this region is usually not pure white but is either pinkish or dark colored. The following section was taken on Little Washita River west of the point where the Frisco Railroad crosses this river. It may be considered a fairly typical section.

[54]Gould, Chas. N., Oklahoma gypsum: Second Bien. Rept. Okla. Dept. Geol. and Nat. Hist., 1902, pp. 110-112.

No.	Description	Feet
5.	Red clay shale	50
4.	Soft rock gypsum, white and pinkish	15
3.	Soft red sandstone	10
2.	Red clay shale	50
1.	Red sandstone along the bed of river	25
		150

"The thickness of many of the ledges in this region is more than that shown in this section. Ledges 50 feet thick are present but it is believed that 15 feet will represent a good average of the Keechi hills locality. Estimating the area at two townships and the thickness at 15 feet the result will be approximately two billion tons for the locality.

"Analysis of gypsum from the vicinity of Cement, Oklahoma, probably a few miles southwest of that town on the Little Washita River.

	Per cent.
Calcium sulphate	74.45
Calcium carbonate	4.25
Magnesium carbonate	.84
Water	18.61
Oxides of iron and aluminum	.61
Silica and insoluble residue	1.02
	99.68

"Analysis of a hard rock from the top of the Keechi hills, Caddo County, Oklahoma.

	Per cent
Calcium carbonate	100.18
Oxides of iron and aluminum	.26
Silica and insoluble residue	.32
	100.76

"West of the Rock Island Railroad on the hills south of the Washita River there are extensive deposits of gypsum in ledges 10 to 20 feet thick. These deposits are first encountered on the hills west of Hog Creek, some eight miles southwest of Anadarko. Along the hills south of the Washita and west of

Hog Creek, between that creek and Fort Cobb, these ledges form the cap rock of the bluff and may be seen for long distances. The cross-bedded, red sandstone below is from 125 to 150 feet thick and the gypsum ledge at the top will average from 15 to 20 feet thick. The extent of these deposits is not definitely known, but gypsums are reported 10 miles south of this line of bluffs. There is certainly an area larger than that of a township. With an average of 15 feet in thickness this will approximate one billion tons for this locality. In appearance this gypsum is white or pinkish and forms ledges of rather soft rock, sometimes partaking of the nature of gypsite. The gypsum in this locality is at the same general level as that in the vicinity of the Keechi hills, or of that across the Washita River to the north.

"The third locality in Caddo County in which gypsum is exposed is along the divide between Cobb Creek and the Washita River northwest of Fort Cobb. The gypsums in this region occur as rounded mounds on the top of the divide. They are in fact but the southeastern extension of the Washita County deposits to the northwest, or perhaps it is more correct to say that they form a connecting link between the Washita County beds and those in Caddo County south of the Washita River. The amount of gypsum in this locality increases as we go up the divide. The most southwestern exposure so far as known is in the northwest quarter of section 13, T. 8 N., R. 13 W. It is a rounded mound occupying perhaps a quarter-section and rising to the height of nearly 100 feet above the surrounding plain, or divide upon which it is situated.

"The amount of material in this part of Caddo County will probably not approximate more than 500 million tons. This will make a total of three and one-half billion tons in the county."

Gypsite beds.—The only gypsite beds of importance in the county are near Cement. One bed of about 30 acres lies principally in the SW. 1/4 sec. 33, T. 6 N., R. 9 W., about one mile north of Cement. The material is a light gray gypsite with little sand. A spur from the Oklahoma City-Quanah branch of the St. Louis & San Francisco Railroad is built to the deposits. Before the burning of the Acme Cement and Plaster Company's mill the material from this bed was used in the

manufacture of plaster. Another bed of 10 acres or more lies about two miles to the north in secs. 21 and 28. Both beds have been largely worked out. The composition of the gypsite bed in sec. 33 is shown in the following analysis:

Analysis of Gypsite From Near Cement.

Calcium sulphate	63.82
Calcium carbonate	4.86
Magnesian carbonate	.14
Iron and aluminum oxides	.69
Water	16.43
Insoluble residue	13.95
	99.89

Development.—No use is being made of the gypsite in Caddo County at present. The mill at Cement which has been mentioned was burned in 1911 and the spur track to the gypsite bed has been partially taken up. Judging from a rather hurried survey, there is not sufficient material remaining to justify rebuilding the mill. The rock gypsum for the mill was secured at Gladys, on a spur from the St. Louis & San Francisco Railroad, about four miles southwest of Cement. This quarry is still operated on a small scale and the rock shipped to Portland cement plants. The analysis given above by Gould is probably of rock from near Gladys.

COMANCHE COUNTY. [85]

"The known outcrops of gypsum in this county are rather unimportant. All the deposits so far as known occupy an area of a few square miles along the north line of the county a few miles northeast of Frisco. The gypsum is exposed in irregular ledges along the slope or on top of rounded hills. The amount of material is not large, perhaps not more than 200 million tons in all. The location of the deposits is such, however, that a number of mills might be profitably located in the vicinity."

[85]Gould, Chas. N., Oklahoma gypsum: Second Bien. Rept. Okla. Dept. Geol. and Nat. Hist., 1902, pp. 110.

GRADY AND STEPHENS COUNTIES.

The outcrop of the Greer formation extends from Caddo and Comanche counties southeast across the southwestern corner of Grady County and into northwestern Stephens County where it disappears. No rock gypsum deposits of commercial importance occur in these counties and the only known deposits of gypsite of importance are in Grady County, four miles west of Rush Springs. One bed of 27 acres lies in the SW. ¼ sec. 23, and another of equal size in the SE. ¼ sec. 22, T. 4 N., R. 8 W. Both beds average about eight feet in thickness. The material was formerly hauled to the mill of the Acme Cement Plaster Company at Marlow. This mill burned a few years ago and a new concrete and steel mill has been erected at the deposits by the same company. A spur track from the main line of the Chicago, Rock Island & Pacific Railway at Rush Springs affords transportation facilities.

SUMMARY OF THE SECOND LINE OF GYPSUM HILLS.

The second line of gypsum occupies parts of Dewey, Ellis, Roger Mills, Custer, Washita, Caddo, Comanche, Grady, and Stephens counties. The gypsums are very thin in the northwestern and southeastern portions of the area and very thick in the central part, in southeastern Custer and eastern Washita counties, where ledges of 60 feet or more in thickness are known. The gypsum varies from white to pink in color and from fine-grained to coarsely selenitic in texture. A part of the lower gypsum is anhydritic in Washita County. The total amount of gypsum in the area is very great but the stratification is so irregular and the transportation facilities are so poor that there has been very little development. Small beds of gypsite occur in practically all the counties, but commercial deposits are known only in Custer, Caddo, and Grady counties. The only mill now operating is at Rush Springs, in Grady County. Mills at Marlow in Stephens County and at Cement in Caddo County have burned during the past few years.

SOUTHWESTERN AREA.

INTRODUCTION.

In the various reports and articles by Gould, this area has been called the Greer County Region and at the time the

first reports were written practically all of the area was included in the County. Since 1907, however, old Greer county has been subdivided and the gypsum area now forms part of Greer, Beckham, Harmon, and Jackson counties. For this reason it is thought best to drop the name Greer County Region and to use instead the term southwestern area, since the area occupies the extreme southwestern corner of the State.

The gypsums of the southwestern area occur in the Greer formation, presumably at the same general level as those of the second line of gypsum hills, and are probably the southwestward extension of those gypsums. The stratigraphy of the gypsums, however, is quite different from that of the second line of hills. Especially in the northern part of the southwestern area, the gypsums occur in well defined ledges which can be traced for considerable distances, and which produce a topography much more similar to that of the first line of hills or outcrop of the Blaine formation, than to that of the second line of hills or eastern part of the outcrop of the Greer formation. In the northern part of the area five ledges of gypsum are well defined and are traceable for many miles. These have been named by Gould as follows, beginning at the bottom: Chaney, Kiser, Haystack, Cedar Top, and Collingsworth.

Gould's description of these gypsum members is given in full.[86]

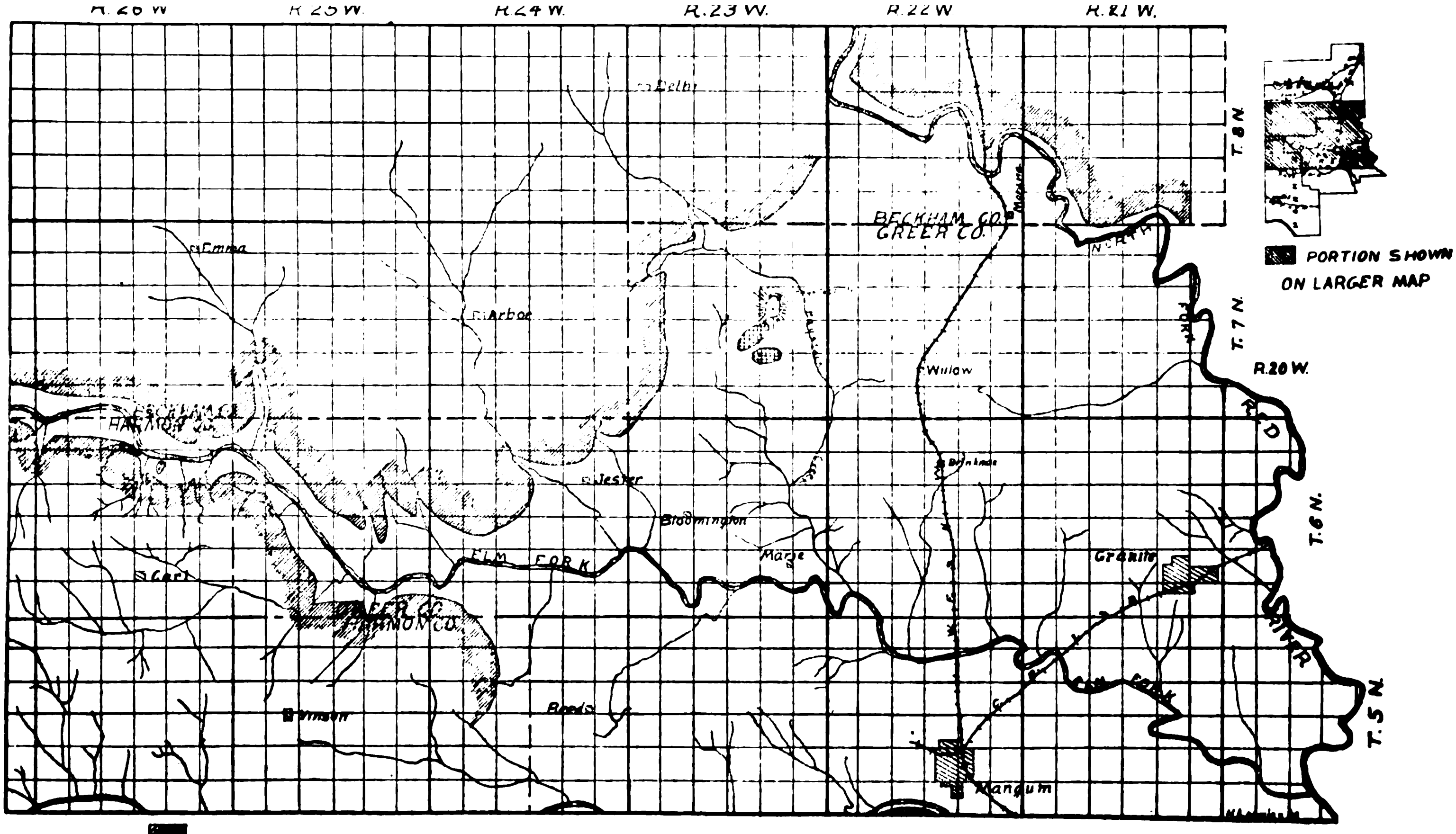
"*Cheney gypsum member.*—This gypsum is well exposed along the south side of Elm Fork from Mangum northeast to the Texas line. It is also seen on Haystack Creek, but on North Fork, in Roger Mills County, (now Beckham), it loses its characteristic structure and becomes simply a gypsiferous band in the red clay. On Elm Fork at the mouth of Hackberry Creek and also at the Kiser and Chaney salt plains near the Texas line, it is a hard massive stratum three to five feet thick, usually white, but sometimes gray or bluish. It is often distinctly stratified or apparently cross-bedded, or it may be that the lines of stratification are wanting. The formation derives its name from the Chaney Salt Plain on Elm Fork of Red River, four miles east of the Texas line.

[86]Gould, Chas. N., Geology and water resources of Oklahoma: Water-supply paper U. S. Geol. Survey No. 148, pp. 66-71.

"*Kiser gypsum member.*—This member is exposed throughout the western area of the Greer formation. It is rarely white and in this regard differs from all other ledges of the Greer. It varies from a decidedly bluish or greenish tint to a drab or gray. On the North Fork it is composed of greenish gypsum and gypsiferous shales becoming hard locally, and on Haystack Creek of bluish and drab gypsum, grading into gypsiferous rock and clay. On Elm Fork, at both the Kiser and Chaney salt plains it is composed of soft, bluish to greenish, selenitic gypsum and at the mouth of Hackberry, 10 miles down Elm Fork, it is a bluish stratified gypsum. These occurrences show that while the general character is fairly constant, the stratum varies considerably in local sections. The softness of the rock renders it particularly susceptible to weathering, and it is frequently inconspicuous. Its thickness varies from one to three feet. The name is from the Kiser Salt Plain on Elm Fork. Greer (now Harmon) County, where the ledge is well exposed.

"*Haystack gypsum member.*—The upper part of the Greer formation consists of three layers of massive gypsum and one of dolomite, interstratified between the beds of red clay shale. The lowermost of the three thicker layers, the third gypsum member from the bottom of the formation, consists of the typically massive gypsum, almost pure white or occasionally grayish in places, with a few thin bands of gypsiferous sandstone. This ledge is often cut by joints which separate the rocks into rectangular blocks. These blocks frequently weatner out and roll down the slope and in places render it conspicuously white for miles. The Haystack varies locally from 18 to 25 feet in thickness, and so far as known is the thickest gypsum member in the western area of Greer. It is exposed along all the bluffs on North Fork and Elm Fork and is particularly conspicuous on Haystack Creek and in the vicinity of Haystack Butte, whence the name.

"*Cedartop gypsum member.*—The Cedartop is a massive white gypsum, very similar in appearance to the Haystack. It has a constant thickness of 18 to 20 feet throughout the region of outcrop. It is very conspicuous on North Fork, Haystack, and Elm Fork, and forms the caps of a number of buttes and bluffs throughout the region. It is called "Cedartop" from a prominent butte on the North Fork of Red River, in the ex-



APPROXIMATE OUTCROP OF GYPSUM

SALT PLAINS AND SPRINGS

MAP
OF A PORTION OF
BECKHAM, GREER AND HARMON COUNTIES

treme southeastern corner of Roger Mills (now Beckham) County. This rock forms the upper ledge of this butte, and may be seen from a great distance up and down the river and even from Headquarters Mountain at Granite, 15 miles away.

"*Collingsworth gypsum member.*—This is the upper gypsum ledge of the Greer formation, and it does not differ materially in lithological appearance from the Haystack or Cedartop. Like them, it is massive and white throughout, and like them, also, it is cut by a series of master joints into rectangular blocks. Where exposed, the thickness varies from 18 to 20 feet, being approximately that of the Cedartop, and not so great as the Haystack. As it is the upper gypsum member it has often been eroded, and for that reason does not always appear in a section. Near the heads of the various creeks, however, it is the prominent ledge, and it is also exposed on a number of conspicuous bluffs, as along North Fork. It is named from Collingsworth County, Texas, just west of Greer (Harmon) County, Okla., where the gypsum is well exposed."

In addition to this general description of the gypsums it seems best to add a brief discussion of the area by counties, as has been done with the other gypsum areas. The locations of the principal deposits in Beckham, Greer, and Harmon counties are shown on the accompanying map (fig 59).

BECKHAM COUNTY.

The available gypsum deposits of Beckham County are in the extreme southeastern part. From the southeastern corner of the county a bluff 150 to 200 feet high extends for 10 miles or more up the south side of North Fork of Red River. This bluff is made up of red shales with four ledges of massive white gypsums, aggregating about 70 feet in thickness. A view of the bluff is shown in figure 60.

The gypsum in this bluff is available to transportation only where the Wichita Falls & Northwestern Railway crosses North Fork, about three miles south of Carter. Immense deposits of gypsum can be opened up on either side of this railroad by short spurs. The estimated amount of material in the bluff is 1,000,000,000 tons. The stratigraphy and nature of occur-

Fig. 60.—Gypsum bluff along North Fork of Red River.

rence of the gypsum is shown in the following section by Gould.

Section of Bluff on North Side of North Fork of Red River. Three Miles South of Carter.

		Feet
10.	Rough, weathered, sandy dolomite capping the high hills	3
9.	Red and green gypsiferous shale	24
8.	Massive white gypsum	23
7.	Red and green shale	6
6.	Massive white gypsum	18
5.	Red and green shale	15
4.	Massive white gypsum, occasional thin ledges of sandstone	25
3.	Reddish and green shale	24
2.	Greenish gypsums and gypsiferous shale, becoming hard locally	5

1.	Red and green gypsiferous shale from the base of the hill	30

Just below the lowest heavy gypsum, No. 4 of the above section, the shales are filled with some of the most perfect selenite crystals observed in the state. The crystals are in the main about one inch long, and about one-half as wide and thick. They form a sort of network with the spaces filled with clay. Some selenite bands of about six inches in thickness are present. These are made up for the most part of exceptionally clear selenite, but occasionally contain beautiful cloud-like masses of some red material presumably ferric oxide or hydroxide, or a mixture of the two.

Gypsum probably underlies about six townships in southwestern Beckham County and outcrops near the heads of Fish and Bailey creeks. These deposits although of considerable size are too far removed from transportation to be considered available at present. The stratigraphy of this part of the county and the immediately adjoining portion of Greer County is shown in the following section. [87]

Section Near Beckham County Line Along Haystack Creek, Six Miles South of Delhi.

		Feet
11.	Red clay	50
10.	Hard sandy rock	4
9.	Red and green clay	20
8.	Massive white gypsum	16
7.	Red and green clay	8
6.	Massive white gypsum	18
5.	Red and green clay	20
4.	Bluish and drab gypsum	4
3.	Red clay	15
2.	Gypsum and hard rock	5
1.	Red clay	100

GREER COUNTY.

The gypsums of the southwestern area are well exposed in

[87] Gould, Chas. N., Bull. Okla. Geol. Survey No. 5, 1911, p. 103.

the extreme northwestern part of Greer County along Elm Fork and its tributaries. All five ledges are usually present and they outcrop on bold bluffs which are usually capped by a thick ledge of dolomite. On the north side of Elm Fork the gypsums become noticeable in the vicinity of Haystack Butte in sec. 14, T. 7 N., R. 23 W. This butte is an outlier of a pronounced range of hills to the west. The butte and hills are capped by the Haystack gypsum which is ten to twenty feet thick. The Kiser gypsum outcrops twenty feet lower on the slope and is three to four feet thick. The Chaney gypsum does not appear to be present. From Haystack Butte the bluff extends westward up Elm Fork. All the streams flowing into the river from the north have cut canyons into the gypsums and indent the line of bluffs deeply. At the mouth of Hackberry Creek the following section was measured.

Section on Elm Fork at mouth of Hackberry Creek.

		Feet.
12.	Hard cap rock, dolomite	3
11.	Red clay	20
10.	Massive, white gypsum (Collingsworth)	18
9.	Red and blue clay	8
8.	Massive, white gypsum (Cedar Top)	20
7.	Red and blue clay	5
6.	White gypsum separated into thin beds by sandy dolomite (Haystack)	18
5.	Red and blue clay	12
4.	Bluish, stratified gypsum (Kiser)	4
3.	Red and blue clay	15
2.	White and bluish gypsum (Chaney)	4
1.	Red and blue clay	8

The gypsum bluffs continue up Elm Fork into Collingsworth County, Texas, and back on the south side almost to Mangum.

Along South Fork of Red River there are prominent gypsum bluffs on the south side of the river at Mangum. These extend up and down the river for some distance but are not so pronounced, especially to the west. The stratigraphy is given in the section taken in Jackson County at the junction of Horse Branch and Salt Fork.

Availibility of the Gypsums.—The gypsum deposits at Mangum are about a mile distant from the Wichita Falls & Northwstern and the Chicago, Rock Island and Pacific railways but are on the opposite side of Salt Fork. The expense of bridging the stream would be quite heavy. The amount of stripping increases very rapidly back from the outcrop and quickly reaches a prohibitive thickness. In view of these conditions it does not seem probable that these beds will be developed in the near future.

The deposits along Elm Fork in the neighborhood of Haystack Butte can be reached by four to six miles of spur track from the Wichita Falls & Northwestern Railway near Willow. The greater part of this distance would be over fairly level ground and the expense of building the switch would not be prohibitive under some conditions. In the present state of the plaster industry in Oklahoma, however, and in view of the immense undeveloped deposits with transportation facilities immediately at hand, it seems improbable that such a project should be undertaken. The deposits farther west along Elm Fork are so far from railroads as to render them unavailable at present.

Gypsite beds.—A large gypsite bed has been reported from secs. 26, 27, 34, and 35, T. 7 N., R. 23 W., two miles west of Haystack Butte. The bed covers about 300 acres and is exposed from four to fourteen feet thick. Reports give the maximum thickness as thirty feet. The stripping varies from nothing to six feet. In character the material is light gray in color and is apparently quite sandy. In one locality, about one-fourth mile north of the section corner near the center of the bed, there are indications that the bed is not true gypsite but rather a very fine-grained, soft, gypsiferous, and argillaceous sand such as is often found in lentils in the Redbeds. In the locality mentioned it is overlain by red clay which has all the appearance of Redbeds shale in place. It is reported that the material has been tested and that it makes a good grade of plaster but neither the name of the parties having the tests made nor the reports of the test are available. If the material is suitable for plaster there is a vast amount of it available under favorable conditions, except in regard to transportation. The bed is about four miles from the

railroad. A spur built to the gypsum deposits near Haystack Butte could pass through the bed with little or no extra expense.

HARMON COUNTY.

All of Harmon County is underlain by the Greer formation but only in the extreme northern part are there good exposures of the gypsums. These exposures are on the bluffs of Elm Fork in T. 6 N., R. 26 W., and are the continuation of the bluffs in Greer County, which have been described. The following section was taken on the bluffs of Elm Fork in the northern part of sec. 10.

Section of Bluff on Elm Fork in sec. 10, *T.* 6 *N.*, *R.* 26 *W.*

		Feet
12.	Dolomite	1-3
11.	Red clay	16
10.	Gypsum (Collingsworth)	11
9.	Red and blue clay	6
8.	Gypsum (Cedar Top)	16
7.	Red and blue clay	5
6.	Gypsum (Kiser)	20
5.	Red and blue clay	15
4.	Gypsum (Chaney)	2
3.	Red Clay	12
2.	Gypsum	3
1.	Gypsiferous, red, and blue clay (about)	60

The clays, especially the lower ones, are filled with selenite crystals and satin spar. At the bluff east of the Salt Plain in sec. 11, the thin lower ledges were not observed. The lowest heavy gypsum occurs about 90 feet above the level of the Salt Plain, is about 15 feet thick, and seems to be anhydritic. The second heavy gypsum is 20 feet thick and is separated from the lower by seven feet of red clay shale. A view of this bluff is shown in figure 61, and a view of the canyon and salt plain in figure 67 in the following chapter of this report. These gypsums are too far from a railroad to be available but other conditions for development are favorable.

The greater part of Harmon County is level and there are few good exposures of gypsum south of Elm Fork. The pres-

Fig. 61.—Bluff east of salt plain in sec. 11, T 6 N., R. 26 W.

ıce of gypsum is shown by sinkholes and by well logs. Prac-
cally nothing can be told of the stratigraphy of the gypsums
·om the meager data at hand. A few small exposures are
ıown along Salt Fork of Red River, but none were observed
'hich could be said to be of commercial importance. In a large
rea around Hollis there are practically no exposures. Gypsum
ɜ reported from wells. Some bowlders of gypsum were re-
noved from the shallow cuits of the Wichita Falls & Northwest-
ɜrn Railway just east of Hollis, but if they represent a solid
edge most of it has been removed by solution. In some of these
:uts the Redbeds appear to be folded into rather sharp folds.
This folding is presumably due to the solution of the underlying gypsum beds. At Gould there is an area of bad lands with some channels 20 to 30 feet deep. These show considerable selenite in clay but no available gypsum. Very little can be determined as to the amount of gypsum present in the southern part of the county and practically nothing as to the stratigraphy of the beds. They are presumably at about the same horizon as the well defined ledges in Beckham, Greer, and the northern part of Harmon County. From the stratigraphy along Salt Fork of Red River near Mangum, a region which in a measure connects the northern and southern portions of the area Gould believes that the gypsum of the southern part are at a slightly lower level than those in the northern part.

Availibility of the gypsums.—Gould estimates the amount of available gypsum in Harmon County, *i. e.*, the amount present at less than 100 feet in depth, at 15,000,000,000 tons. However, the gypsum in the northern part of the county is so far removed from transportation that it can not be utilized at present. It is difficult to make any definite statement concerning the deposits of the greater portion of the county, but judging from surface appearances along the only line of railway, the Wichita Falls & Northwestern branch from Altus to Wellington, Texas, the beds are so deeply buried that their utilization seems impossible. There is certainly little promise of development of such deposits while so many large deposits, with more favorable conditions as regards quarrying or mining, and with as good or better location in regard to fuel and transportation, remain undeveloped.

Gypsite beds.—Little search has been made for gypsite in the county and only a few small beds are known. A bed covering 10 to 15 acres and varying in thickness from three to six feet is reported in the NW. 1/4, sec. 1 ,T. 2 N., R. 25 W., and adjoining parts of the sections to the north and west. This bed is less than one mile from the railroad. A bed of about 10 acres in area and three to six feet in thickness lies in sec. 6, T. 1 N., R. 24 W.

JACKSON COUNTY.

The Greer formation underlies the western half of Jackson County. The gypsums are more prominent than those in southern Harmon County but much less so than those of northern Greer and Harmon counties. The stratigraphy is usually irregular. The best exposures are on Horse Branch and Boggy Creek.

Gould gives the following sections showing the stratigraphy in the south-central part of the county:

Section of bluff between Salt Fork and Horse Branch near Olustee.

		Feet.
12.	Hard rock, dolomite, forming the cap of the hill	3
11.	Red and blue clay	12
10.	Massive, white gypsum	8
9.	Red clay with ledges of gypsum	24

8.	Massive, white gypsum	12
7.	Red and blue clay	15
6.	Red and blue soft, shaley rock and gypsum	5
5.	Red and blue shaley clay	22
4.	Bluish gypsiferous rock	10
3.	Red and blue clay	8
2.	Massive, white gypsum	3
1.	Red clay slope from Horse Branch	100

Section on Boggy Creek nine miles northeast of Eldorado.

8.	Hard, massive rock, dolomite, forming the cap of the bluffs	5
7.	Red and green shale and clay	30
6.	Massive gypsum	10
5.	Red clay	5
4.	Clay and hard rock	5
3.	Massive white gypsum	15
2.	Red and blue clay	25
1.	Hard, massive gypsum exposed in creek bed	15

In the hill just west of Creta on the St. Louis & San Francisco Railroad, two massive ledges of white gypsum are exposed. The lower is about 15 feet thick and the upper about 12 feet. The upper ledge is covered by about 30 feet of red shale and 6 to 20 feet of dolomite. The slope of the hill is so steep that comparatively little of the gypsum can be obtained without excessive stripping so that mining methods would be necessary. This in itself would not be sufficiently expensive to be prohibitive but, in view of the general conditions of the gypsum industry in Oklahoma, mining methods cannot be considered as feasible at present. Some outcrops of gypsum are known to the west of those described but they are generally small and unimportant.

Availability of the gypsums.—The principal exposures of rock gypsum in Jackson County can be easily reached from the St. Louis & San Francisco Railroad. The main hindrance to their development is the thick cover due to the Mangum dolomite capping the hills and preventing the erosion of the shale from above the gypsum. Mining methods would be necessary to utilize the gypsum, and as has been said, these methods would be too expensive to be feasible at present.

Gypsite beds.—The gypsite beds of Jackson County are

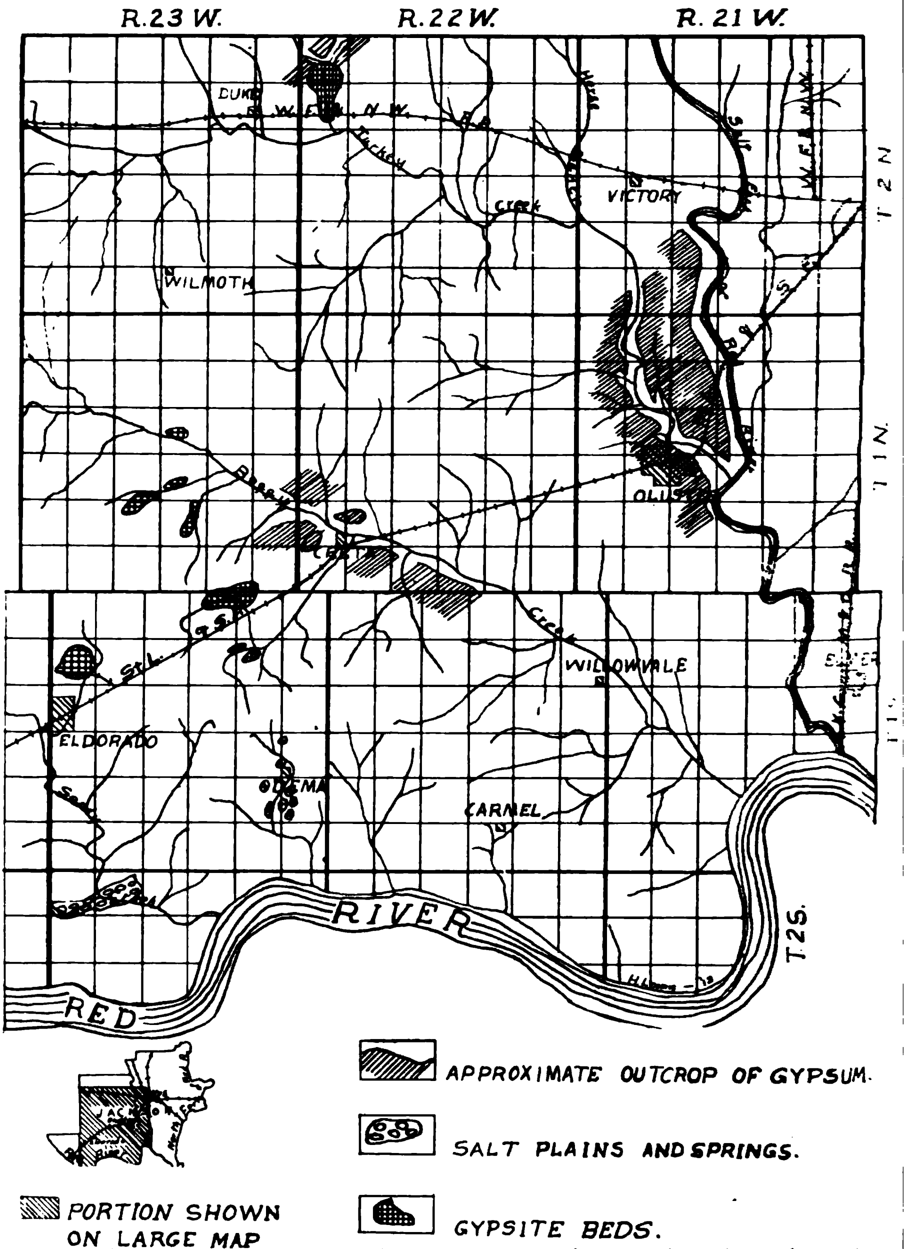


Fig. 62.—Map of portion of Jackson County showing location of gypsite beds and salt plains.

among the most important in the State. They are of large extent and are well situated in regard to transportation. The location of the principal beds is shown on the accompanying map (fig. 62). The largest bed known in the county covers about 400 acres in sec. 7, T. 1 S., R. 23 W., just north of the town of Eldorado. The thickness of the gypsite varies from 8 to 20 feet with little or no stripping. The Eldorado plant of the United States Gypsum Company is situated at the bed and is reached by a spur from the St. Louis & San Francisco Railroad. The company owns this bed and also controls a bed in secs. 2 and 3 of the same township. This bed covers about 140 acres and is 6 to 12 feet thick. The railroad passes near the east end of the bed. Two smaller beds lie in secs. 10 and 11. Together they cover 40 to 50 acres and are 6 to 12 feet thick. Smaller beds lie in secs. 24 and 25.

In the townships to the north there are seven or eight small beds in secs. 21, 22, and 27. The aggregate area is about 40 acres and the depth of the deposits varies from four to eight feet. The beds are between two and three miles from the railroad.

A gypsite bed of approximately 375 acres lies in secs. 6 and 7, T. 2 N., R. 22 W., one mile east of Duke. The Altus and Wellington branch of the Wichita Falls & Northwestern Railway crosses the southern part of the deposit. A creek flows from north to south and through the deposit and exposes rock gypsum of about six feet in thickness along its banks for the greater part of the length of the bed. A lower ledge of gypsum is separated from the one best exposed by a few feet of red shale. The thickness of the lower bed could not be accurately determined. The gypsite is six to eight feet in thickness and has up to two feet cover. Over considerable areas the gypsite lies at the surface. The gypsite is light gray near the surface but grades into pink and reddish-brown in the lower parts of the bed.

CHAPTER VI.

THE SALT PLAINS OF OKLAHOMA.

INTRODUCTION.

Salt is closely associated with gypsum in origin and occu rence and as these points have been rather fully discussed i Chapter I they need not be noticed further here. Salt may b mined from beds of rock salt or may be obtained from brine b evaporation. The processes used in evaporation vary greatl with conditions, but, in view of the present condition of the sal industry of this State, it is not thought worth while to go int a discussion of these features.

Wells and springs of salt water occur in all parts of Okla homa. Salt water is often encountered by deep borings in dif ferent parts of the State. This is especially true in the oil an gas fields. So far however, no investigations have been mad as to whether the brines from these deep wells are sufficientl concentrated to be used in the manufacture of salt. In only on place, to the writer's knowledge, has salt been manufactured i the eastern part of the State, viz: at the flowing salt well o Grand River southeast of Choteau in Mayes County.

All that is attempted in this chapter is to give a brief de scription of the salt plains which occur in the western part o the State in the region of the gypsum hills, and to give brie statements in regard to the conditions of and prospects for de velopment of these plains. The plains described are as follows a plain east of Cherokee in Alfalfa County, two plains on Cim arron River in Woods, Harper, and Woodward counties, a plai on Salt Creek west of Ferguson in Blaine County, a plain o North Fork of Red River south of Carter in Beckham County two plains on Elm Fork of Red River in northern Harmon Coun ty, and three plains on Sandy Creek south of Eldorado in Jack son County.

ALFALFA COUNTY SALT PLAIN.

The Alfalfa County salt plain lies south of Salt Fork of Arkansas River principally in Tps. 26 and 27 N., R. 10 E., about four miles east of Cherokee. The plain is elliptical in shape with the long axis in a north and south direction. It covers approximately 60 square miles. The surface of the plain is almost perfectly flat, and, except for a few hammocky grassy mounds near the edge, is entirely devoid of vegetation. The surrounding country is somewhat higher than the level of the plain, but the difference in elevation seldom exceeds 20 feet and is usually considerably less than that. The material composing the floor of the plain is silt and a very fine sand. The surface of the entire plain is usually covered with a thin crust of salt crystals which glisten in the sunlight. This crust is dissolved by rain and when the surface of the plain is wet it appears as an ordinary level strip of ground. There are no salt springs on the plain or around its margin and no streams flow across it in ordinary weather. When a hole is dug into the sand and silt, salt water rises until the hole is filled to within about six inches of the top. This brine is quite strong, nearly if not quite saturated. The analysis[88] of the material dissolved in it is as follows:

Analysis of water from salt plain at Cherokee.
In parts per million.

Soda (Na_2O)	150,013
Potash (K_2O)	205
Lime (CaO)	1.524
Magnesia (MgO)	1.739
Chlorine (Cl)	152,100
Sulphates	362
Sodium bicarbonate ($NaHCO_3$)	6,235
Iron and aluminum oxides (Fe_2O_3 and Al_2O_3)	36

This shows a total of 250,779 parts of sodium chloride per million, or approximately 25 per cent of salt as it is probably combined. The amounts of impurities present does not appear great enough to interfere with the recovery of the salt on a commercial scale.

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[88]All analyses are by Frank Buttram, Chemist Oklahoma Geological Survey.

Origin of the salt.—The source of the salt of the Alfalfa County plain is not easily seen. It is generally supposed by those living in the vicinity that a bed of rock salt underlies the plain but there is no evidence to support this idea. Saltwater is encountered in wells around the margin of the plain at depths of 20 to 30 feet but to the writer's knowledge no beds of rock salt have been found. It seems probable that the salt water is derived from springs from the Redbeds which have their outlets below the sand and silt of the plain. The flow from the springs and the conditions of drainage into Salt Fork must be such as to raise the level of the salt water to within a few inches of the surface of the plain but not to cause springs to break out through the sand and silt. The water probably obtains its salt from saliferous layers in the Redbeds.

Conditions for development.—No salt has so far been manufactured from this plain. However, the conditions are such as to render its development probable at any time. The western margin of the plain is only four miles from the Kansas City, Mexico & Orient Railroad and the Atchison, Topeka & Santa Fe Railway at Cherokee, and the southern margin is less than that distance from the latter railway west of Jet. The country between the railways and the plain is very level and spurs could be easily constructed. It is impossible to estimate the amount of salt available on the plain. When holes are dug in the plain they fill up very rapidly but no pumping tests have been made to determine whether or not the level of the water can be easily lowered. When the area of the plain is taken into consideration, however, it seems evident that the supply of salt water is sufficient for a very large production of salt even when all adverse conditions are taken into account. The water would have to be obtained from wells sunk in the plain. The soft, caving nature of the sand and silt would make it necessary for these wells to be walled up in some way. The silt remains in suspension in the water for a considerable time and settling basins would probably have to be provided for the water as pumped from the wells. These conditions would probably put some difficulties in the way of the utilization of the brine but they could certainly be easily overcome if development on a large scale should be undertaken.

SALT PLAINS ON CIMARRON.

The two salt plains on the Cimarron in Oklahoma are known

as Little and Big Salt Plains. Little Salt Plain lies just south of the Kansas line between Harper and Woods counties. Big Salt Plain lies 15 to 20 miles farther down the river between Harper and Woodward counties on the southwest and Woods County on the northwest. These plains were visited by the writer in the fall of 1912 but he has nothing to add to the description given by Gould[89] which is:

"Perhaps the most noted of the salt plains, from the standpoint of a historian, is the Big Salt plain of the Cimarron. The first white man to visit this place was probably Coronado, in his journey across the plains in search of the seven cities of Cibola. In regard to this event Mr. J. R. Mead says: 'The route or trail of Coronado, in his famous expedition from the Pueblos of New Mexico across the prairies of Kansas to the populous tribes of the Missouri, will ever remain an open question. The only point we can locate with reasonable certainty is the salt plain of the Cimarron, just within the Kansas line—the only place where rock salt can be obtained on the surface in all the plains country. This salt was known and used by the Indians,, and was an article of trade from the Gulf to the British line, and this locality was a well-known geographical point, from which distances were reckoned.' The presence of a dozen or more trails, now nearly obsolete, radiating from the plain like spokes of a wheel, bears testimony to the fact that this place was long used as a source of supply of salt to the various forts and settlements of the surrounding regions. Indeed, it is but a few years since salt from this plain was hauled for hundreds of miles in all directions, and not until the time of discovery of extensive beds in central Kansas did this industry wane.

"The Big Salt plain proper extends for eight miles or more along the Cimarron river. In width it varies from half a mile to two miles. On the south bank the bluffs of red shale and sandstone capped with gypsum rise directly from the edge of the plain to the height of 100 feet or more. North of the plain these bluffs are not so steep, and are at a distance of a half mile or more from the plain. Even here, however, the sinuous white line of gypsum may be traced along the tops of the bluffs as far as the eye can reach. In other words, the plain lies in the broad

[89]Gould, Chas. N., The Oklahoma Salt Plains: Kans. Acad. Sci., vol. 17, 1901, pp. 182-183.

canyon of the Cimarron, enclosed on both sides by gypsum-capped bluffs of red shale.

"The plain is flat and as level as a floor, except for a few meandering channels which, in wet weather, contain a small stream, but are ordinarily dry. After a rain it will sometimes happen that a stream of considerable volume flows over the plain, but during the summer months nearly all the water either evaporates or sinks into the sand. In places where a small stream still runs down the channel the water is often so salty that a thin crust of crystal white salt forms on the surface, resembling nothing so much as a sheet of ice across a small stream in winter. The entire plain is covered with a thin incrustation of snow white crystals. In most places this incrustation is not to exceed an eighth of an inch thick, but it reflects the sunlight and blinds the eye like a snowfield. Especially if the wind is blowing the small particles of salt, a walk across the plain makes the eyes smart and burn in a manner not easily forgotten.

"In a large cove on the south side of the plains proper, there are a number of salt springs which boil up out of the flat surface of the plain. The water is crystal clear, and it sometimes requires more than ocular proof to convince one that it contains nearly fifty per cent of salt. There are scores, perhaps hundreds, of these springs on an area of a few acres in extent. Some of them flow streams as large as a man's arm; others are much weaker. In all cases their presence is marked by a conspicuous white incrustation of salt, which forms around the spring and along the sides of the little stream that flows from it. Particles of grass or weeds blown into these springs or streams soon become covered with white salt crystals. These strings of crystals are often an inch or more in diameter and look like rock candy. In places the incrustation around the springs are so thick that the salt may be scraped up and hauled away. This is the source of the so-called rock salt of the plain.

"The Little Salt Plain is located a few miles further up the Cimarron, just on the border of Kansas. It does not differ materially from the plain just described, except that it is much smaller and the bluffs on either side of the river are neither so high nor precipitous."

Two views of Big Salt Plain are given in figures 63 and 64.

Fig. 63.—View of Big Salt Plain on Cimarron River.

Fig. 64.—Gypsum capped bluff at edge of Big Salt Plain.

The crust of salt near the springs near the southwestern corner of the Big Salt Plain was about six inches thick at the time of the writer's visit and is reported to reach a thickness of one foot during long continued dry spells. A view of a small area where the crust is between one and two inches thick is shown in figure 65.

Fig. 65.—Salt crysals on surface of Big Salt Plain.

Prospects for development.—The amount of saturated brine going to waste on these two salt plains is very difficult to estimate but is undoubtedly very large. One of the largest springs on Big Salt Plain forms a stream over a foot broad and three inches deep. There are many other springs and besides a very large amount of water probably works out through the sand. The brine is practically saturated as is shown by the formation of the thick crusts of salt over the streams from the springs, and by the formation of crystals on leaves, weeds, and grass which are blown into pools of water. The crystals formed are cubical and appear to be of pure salt. The water from the larger springs is perfectly clear and would not require settling before evaporation. The conditions at the plains themselves, then, seem to be entirely favorable for the development of a considerable industry but the plains are so far removed from railway transportation that there can be no development on a large scale under present conditions. The nearest railroad is about 25 miles from Big Salt Plain and this distance is prohibitive.

In the early days of Oklahoma Territory salt from this plain supplied the local demand for miles around and there was quite a thriving industry on a small scale. However, when the railroads were built through the territory it became possible to ob

tain the imported salt in most of the region formerly supplied from the Salt Plains more cheaply than it could be hauled from the plain. The market was thus greatly restricted while the plains were still left so far from the railroads as to render them incapable of development. The amount of salt manufactured at the plains in the past few years has been almost negligible and there is no prospect of improved conditions until a railroad is built near the plains.

BLAINE COUNTY SALT PLAIN.

Blaine County Salt Plain lies near the head of Salt Creek about four miles west of Ferguson. These springs issue from a red and blue mottled cross-bedded sandstone which outcrops about 100 feet below the Ferguson gypsum. The upper or western part of the plain is in two narrow canyons in the gypsum hills. In this part of the plain there is little sand in the beds of the streams and the water flows for the most part on the red and green shales and the sandstones. One canyon extends east and the other joins it from the north. Below the junction of the two branches the stream flows east, in a canyon so narrow that the salt plain is not over 100 yards wide for some distance but gradually widening as it leaves the gypsum hills until the salt plain is one-fourth mile wide. After the canyon begins to widen, the floor is covered with sand to a depth of several feet. About two miles below the springs other streams join the main creek and the water is so diluted that the salt is not formed on the surface of the sand. The crust of salt formed over the plain itself is much thinner than that formed on the Big Salt Plain. It seldom exceeds one-half inch in thickness and is usually much less than that.

Three samples of the salt water were collected, one each from the north and the west canyons and one from the stream below the junction of the two small streams. The three analyses agree prettly closely, as will be seen from the following table:

Analyses of water from Salt Creek four miles west of Ferguson. In parts per million.

A. Water from stream in west canyon.
B. Water from stream in north canyon.
C. Water from below junction of the two streams.

	A	*B*	*C*
Soda (Na_2O)	146,273	121,715	140,056
Potash (K_2O)	251	328	297
Lime (CaO)	3,516	3,280	3,588
Magnesia (MgO)	1,532	1,097	1,427
Chlorine (Cl)	150,400	123,600	143,200
Sulphate (SO_4)	3,768	5,043	4,356
Sodium bicarbonate ($NaH\ CO_3$)	84	101	100
Iron and aluminum oxide (Fe_2O_3 and Al_2O_3)	176	24	28

Prospects for development.—Blaine County Salt Plain furnishes enough brine to make a large amount of salt. From some approximate measurements it is estimated that enough water could be obtained just below the junction of the two canyons to supply a plant having a capacity of eight to ten carloads per 24 hours. These figures do not take account of the water in the sand at the location where the measurements were made. The water could be obtained by leading it from the streams through sluices to tanks or by pumping from wells in the sand. The plant could be located at Ferguson on the Chicago, Rock Island & Pacific, about three miles from the lower part of the plain or a spur could be easily built up Salt Creek to a plant located at the plain.

From the standpoint of economic importance, Blaine County Plain bids fair to exceed all others in the State, as it is nearer both to the coal fields and to market than the others. A number of primitive salt plants have at different times been located along the edge of the plain. The methods employed in securing the salt are extremely simple. A well is dug in the sand of the plain and the water pumped by hand into vats and evaporated by boiling. Fuel, chiefly cedar and oak wood, was formerly obtained from the canyons near by. It is stated that three buckets of brine will make one bucket of salt. The capacity of one of the plants is said to have been from 500 to 2,000 pounds per day. The salt was hauled in wagons to supply local trade, and the demand is said to have exceeded the supply for a number of years.

A few years ago a plant with a capacity of 450 barrels per 24 hours was erected at Ferguson, the nearest railroad point to the plain. The brine was obtained from open and drilled wells and was carried two miles in a 2½-inch wrought iron pipe. Steam was employed to operate the rakes, elevators, conveyors,

etc. The pans were of cement 12 by 50 feet and 20 inches deep. The plant remained in operation but a few months, when it was purchased by one of the large salt companies and shut down. It has since been dismantled.

BECKHAM COUNTY SALT PLAIN.

This plain was not visited by the writer so Gould's[90] brief description is given:

"In the southeast corner of Beckham County, near Carter, on sections 10, 11, 14, 15, Township 8 North, Range 22 West, is a salt plain occupying an area of about 40 acres. This plain, which is about half a mile distant from the North Fork of Red River, is located near the base of the Gypsum Hills. In places, springs of salt water issue directly from beneath gypsum ledges, while in other instances the water boils up in the form of bold springs from the level surface of the plain. There are more than 20 springs, the waters of which unite to form a stream as large as a stove pipe. In view of the fact, however, that a great part of the water sinks into the sand, it is probable that this amount represents but a small part of the actual flow. Salt has been manufactured at this plain at various times."

This plain is now near transportation, as the Wichita Falls & Northwestern Railway passes within less than a mile of the plain about three miles south of Carter. A view of a spring issuing from beneath a gypsum ledge is shown in figure 66.

HARMON COUNTY SALT PLAINS.

Harmon County salt plains are situated on the south side of Elm Fork of Red River in secs. 4 and 11, T. 6 N., R. 26 W. The salt springs boil up from the floor of the plains, a short distance back from the river. On the plain in sec. 4 there are several springs whose waters vary from fresh to saturated brine. The few springs on the plain on sec. 11 have a flow of almost concentrated brine. The area of the plain in sec. 4 is about three acres and that of the plain in sec. 11, about one acre. The plains are in narrow canyons between hills formed by the Greer gypsums. Salt has been manufactured at both of these plains for several years. Formerly the timber which grew in the can-

[90]Gould, Chas. N., Salt: Bull. Okla. Geol. Survey No. 6, 1910, p. 71.

Fig. 66.—Salt Spring issuing from beneath gypsum ledge, Beckham County.

yons was used as fuel but this has been exhausted and solar evaporation has been used for sometime. The water is led from the springs into large tanks or ponds on the floor of the plain. These are built of slabs of rock. The water is fed into the tanks as desired and as it evaporates a crust of salt forms on the surface which settles to the bottom forming a hard crystalline layer of salt. This layer is broken up with picks and the salt shoveled or raked into piles at the edge of the tanks. A view of the plain in sec. 11, showing the tanks and piles of salt is shown in figure 67. A sample of salt taken from the piles analyzed 99.15 per cent sodium chloride. The principal impurities are sodium and calcium sulphates, and iron and aluminum oxides which probably are in the form of dust which is blown onto the piles. Only a very small portion of the available brine is utilized at either plain.

For several years these plains supplied the market for a large territory but the building of railroads has lessened the area in which the salt can compete with the imported product, with-

Fig. 67.—View of salt plain in Harmon County.

out making the plains themselves accessible to transportation. In times past the production from the two plains reached as much as 600 tons per year but of recent years the output has been much less. There is no prospect of any marked increase in production unless a railroad should be built near the plains.

JACKSON COUNTY SALT PLAINS.

The salt plains of Jackson County are three in number and they lie close together on the west side of Sandy Creek about three miles from its mouth and about the same distance south of Eldorado. The northern plain lies in the E. ½ sec. 31, T. 2 S., R. 23 W., the middle one in the NE. ¼ sec. 5, T. 3 S., R. 23 W., and the southern plain in the NW. ¼ sec. 5 of the same township and range. All three plains are on small tributaries which flow northeast into Sandy Creek. The northern and southern plains are each about 100 yards wide and 400 yards long, while the middle plain is only 40 yards wide but is about one-fourth mile long. The water comes from numerous springs which boil up from the sand along the streams. The sandy floor

of the plains is covered by a thin incrustation of salt. The crust of salt is very thin and the water does not seem to be nearly saturated. Minnows were observed in the small streams swimming up almost to the springs. The water has a very strong taste but is bitter rather than salt.

Some of the incrustation was scooped up with the sand and leached out with water in laboratory. The analysis of the soluble salts show that there is much more sodium sulphate than sodium chloride present and that the potassium sulphate is also high. In the incrustation from the middle plain the proportion of sodium chloride is greater but there is sufficient sodium and potassium sulphates to make the commercial recovery of the common salt questionable. It is possible that the potassium sulphate from the middle plain might be utilized as a by-product. Calcium sulphate is present in greater proportion than it is on any of the other plains investigated.

DATE DUE
